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HIGH "G" TELEMETRY FOR BALLISTIC RANGE INSTRUMENTATION

W. H. Mermagen

RDT & E Project No. 1M010501A005

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

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WHMermagen/paf
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ABSTRACT

The development of a radio frequency telemeter capable of being launched from hypervelocity guns at accelerations up to 250,000 "g" and subsequently measuring such parameters as heat transfer, damping coefficients, infra-red radiation, etc., is described. The need for such a telemeter is discussed and its feasibility is demonstrated. The results of component testing, circuit design and prototype firings are presented.

TABLE OF CONTENTS

INTRODUCTION

In the past several decades, the ballistic range has become a prominent tool in aerodynamics and aerospace physics research. The aeroballistic range consists essentially of a launching device, usually a gun or a gun system, and an instrumented flight path through a chamber in which the pressure and temperature of the environmental gases can be controlled. A pressure-temperature controlled range can be used to simulate upper atmosphere conditions or to produce an environment with gases other than air. The Ballistic Research Laboratories have several such ranges which have been described in detail by Braun[1] and Rogers[2]. Conventional, single-stage, propellant guns, as well as multi-stage, light gas guns are available.

The customary instrumentation for these free flight ranges consists of spark shadowgraph stations, photocell triggering and velocity measurement apparatus, high speed framing and smear cameras, schlieren stations and optical interferometry. With such instrumentation, one can make accurate measurements of drag, aerodynamic forces and moments, electron densities and shock wave parameters. These instruments will not, however, give direct measurements of such dynamic variables as stagnation temperature, energy transfer and damping coefficients, and other physical quantities associated with flight at high velocities. Some years ago, it was realized that an active and direct in-flight measuring apparatus would be valuable and in some cases the <u>only</u> technique for obtaining data from a high velocity model moving through a controlled range. It was seen that an active radio telemeter would fill these requirements. Radio telemetry has been widely used in industrial processes and in rocket and missile control systems. But, radio telemetry in such applications has been used in what might be called a relatively mild test, one certainly not involving the severe shocks and accelerations experienced in gun launchings. Therefore, the question of whether electronic circuits can survive gun launchings and continue to function thereafter was the most serious and immediate problem. World War II experience with VT fuzes gave some confidence that a 10,000 "g" - 3 millisecond launch impulse could readily be survived. Advances in solid state technology gave rise to the hope that a 100,000 "g" - 3 millisecond impulse could also be weathered. Later experience showed that with proper packaging a 250,000 "g" - 5 millisecond impulse was not even an upper limit.

A contract was let with the Harry Diamond Laboratories (then called the Diamond Ordnance Fuze Laboratories) to develop such a high "g" telemeter. At the same time, similar programs were in progress at the Canadian Armament Research and Development Establishment (CARDE) under Bull[3] and at the Arnold Engineering and Development Center (AEDC) under Kingery[4] and others. (A bibliography of work done in the field of high "g" radio telemetry has been compiled by Clemens[5].) At the outset of the BRL-HDL program, little was known about the effects of extremely high accelerations on electronic components, sensors, circuits and potting materials. First, components were evaluated both by theoretical studies and by test firings from guns. The results of this program have been reported in part[6]. After a number of suitable components and materials were found, entire circuits and modules were developed and tested in guns. Finally, after some years of effort, complete telemetering systems were constructed and flown. A substantial number of these systems were tested during the past two years while constant improvements and refinements were being made. At present, the initial development program is considered at an end. Work progresses on sensor development, improved accuracy, multiple channel operation and increased power.

DISCUSSION OF THE PROBLEM

The first step in the development of the high "g" telemeter was to determine which dynamic variables could be measured by an active radio telemeter. It was thought that a temperature measurement would be the most straight-forward and simple to verify. Base pressure measurements in the region behind the projectile were also considered but reliable sensors were not immediately available. The measurement of accelerations normal to the flight axis was quite attractive but required the building of a rugged solid state accelerometer. Infra-red radiation measurements were considered a possibility, but were dependent on the durability of devices such as lead sulfide cells. So the development proceeded initially in the direction of temperature telemeters.

Guns which are available as test launchers vary in size from 20 to 105mm and are capable of producing velocities up to 20,000 fps with vehicles weighing from 5 to 500 grams. Some of these guns, such as the 37mm, the 90mm T208, and the 105mm T210, were conventional propellant guns. Others, such as the 20mm, the 0.50 caliber, and the 240-176-76mm, were light-gas guns. The 105mm gun has a maximum operating breech pressure of 60,000 psi and for a total sabot-projectile weight of four pounds, accelerations up to 200,000 "g" for four milliseconds could be expected in the barrel.

It was apparent that only solid state electronic devices would survive the 200,000 "g" environment and that they would have to be potted internally. Capacitors and resistors would have to be of monolithic construction and as small as possible. Batteries for the power supply would have to be solid core cells. The entire finished circuit would require potting and the final projectile would have to be a solid mass of nearly uniform density - including the circuit elements. To minimize the chance of failure, initial circuits would be made very simple and would probably not be of optimum design. The transmitted power had to be great enough to enable transmission over a range of 250 ft., since, for horizontal firings through the range, antennas could be placed along the flight path.

Sensors would be designed on the basis of ruggedness and simplicity. Thus, for example, mechanical accelerometers were not considered. Surface temperature sensors would be thin-film, resistance elements. Piezoelectric crystals would be used for accelerometers. Variable capacitance gages might be useful for pressure measurements.

Finally, the ground receiving station had to be implemented. Dipoles or long wire transmission lines were considered for antennas. The possibility of using the range chamber itself as an antenna was studied. In order to avoid the problems associated with amplitude error in an AM telemetering system, the telemeter would be operated in FM and, therefore, FM receivers would have to be coupled to the antennas. Wideband receivers were suggested since there would probabily be unpredictable shifts in carrier frequency due to the high accelerations at launch. The signals received by the FM receivers would be recorded and magnetic tape was thought to be most suitable for the task. The tape would be played back into an oscillograph recorder for a graphic record of the data. This record could then be further reduced by an optical comparator or a telereader. Or, the data could be fed from the recording tape directly into a subcarrier discriminator for direct analog output of data.

MECHANICAL TECHNIQUE

A variety of components such as transistors, capacitors, resistors and batteries was obtained after careful evaluation for inherent ruggedness of design. These components were encapsulated in cylindrical proof slugs made of aluminum and fired at both the BRL Transonic Range and the HDL Range. Early firings at Transonic Range were done with a 37mm gun, and the slugs were recovered in a cylindrical tank filled with polystyrene beads. At HDL, the potted slugs were launched from an air gun and allowed to impact on a steel plate. The impact gave a high "g" pulse whose amplitude depended on impact velocity and the shape of the slug. The pulse duration was short, of the order of less than one millisecond. Since air gun tests could not provide a 200,000 "g" pulse, they were eventually discontinued. The results of similar tests done at AEDC[7] and at CARDE[8] were taken into consideration in the selection of components suitable for high "g" work.

Transistors were tested in the above fashion both with and without internal potting. It was found that most transistors required internal potting in order to survive more than 40,000 "g". For a long time internal potting of transistors was an arduous task and the yield of good potted transistors was low. This was due in great part to the degradation that occurred as soon as the transistor protective casing was removed. A technique for rapidly coating the transistor junction was developed to inhibit degradation. A coating compound consisting of a mixture of Dow Corning Sylgard 81 dissolved in triple-distilled chloroform was applied to the transistor junction as soon as the casing had been broached. The mixture was injected by means of a hypodermic syringe into the first possible opening made. The rest of the casing could then be opened at leisure. As soon as the top of the casing had been lifted off, more of the Sylgard-chloroform solution was added. The excess was shaken off and the solution left on the junction quickly evaporated, leaving behind a thin coating of Sylgard on the junction. Now the transistor was ready for further potting. First attempts at filling the case with a hard epoxy such as Epon 815 showed that shrinkage occurred during the curing process. This shrinkage created voids and pockets between the potting material and the side walls of the case. In addition, internal stresses were built up in the potting compound which would often ruin the transistor. This difficulty was substantially relieved by combining an inert filler such as powdered silica in a one-to- one ratio with the epoxy resin. Whereas previously there had been a failure rate, due to stresses, of about six in ten transistors potted, now the failure rate dropped to one in ten. The curing agent for Epon 815 is DETA (di-ethylenetriamine) and is used in proportions of ten parts per hundred of resin. 2N502 transistors potted by this technique showed remarkable insensitivity to high accelerations and had a shelf life of more than one year.

Once transistors had been potted and suitable passive elements had been selected, entire circuits such as oscillators and amplifiers were constructed. At first, printed circuits were tried but were found to fail under high accelerations. In the final design, components were aligned on fiberglass boards in such a way as to economize on space, reduce lead lengths and put least sensitive axes along the direction of maximum acceleration. Welding of electrical connections was attempted but the results were not as good as with simple solder joints. (Either the welding process produced a greater number of poor connections than did soldering, or the welded connections themselves do not make good high "g" joints.) The most satisfactory wiring technique was a straight point-to-point one using no insulation. It was felt that insulation tended to permit some freedom of motion for the lead wires which might cause a break during the high acceleration.

Wherever long leads could not be avoided, such as between the surface detector and the circuit, these leads were zigzagged to provide some slack.

Complete projectiles were assembled and the projectile bodies potted with Epon 815. It was soon found that a solid Epon 815 plastic by itself tended to be too brittle for gun launching. The brittle quality of the Epon mix was reduced substantially by adding a liquid polymer. Thiokol LP-3 was chosen and used in a 60-40 resin to polymer ratio. Not only did the LP-3 make the plastic more resilient but it also inhibited the formation of internal stresses. The proportion of DETA catalyst was kept at six parts per hundred of mix. The nature of resin-polymer systems has been investigated by Thiokol Corp. and data are available in the manufacturer's private literature.[9] The curing process for Epon 815 is exothermic and temperatures as high as 300°F have been observed in 500 gram batches. The temperature can be kept low by potting in stages, a small amount (say 50 - 100 grams) at a time. The excessive temperatures produced in potting large quantities at a time could damage electronic components and do produce bubbles and cavities in the final plastic.

Epon 815 LP-3 plastic will burn, and heat shields in the form of steel windscreens had to be provided for the telemetering vehicles. Some projectiles were of such a shape that windscreens could not be used. For these, a fiberglass shell was developed. The fiberglass was woven on a mandrel to the approximate shape of the projectile while being continuously wiped with epoxy resin according to a Naval Ordnance Laboratory (NOL) process. The resulting projectile would not burn even at velocities approaching Mach 10.

DEVELOPMENT OF THE TELEMETER

As soon as an adequate number of high "g" components had been found and tested, work began on circuit development and the fabrication of prototypes. The initial effort was put into the development of a temperature sensing telemeter followed by the development of acceleration sensing telemeters, vertical probe telemeters and infra-red sensing telemeters.

Temperature Telemeter

Sensor. The sensor was of primary importance in the development of the temperature telemeter, since the circuitry for the telemeter would certainly be dictated by the nature of the sensing device. Bead thermistors, thermocouples and thin films were thought to be the most rugged types of temperature gage. Since heat transfer calculations can be considerably simplified by assuming the surface to be planar and uniform, any gage which would appreciably protrude from or disturb the surface would certainly introduce complications in the calculation. This immediately ruled out the use of bead thermistors and semiconductive thermoelectric devices. Thermocouple gages suffered the disadvantage of producing low level (millivolts) signals which would require a stage of amplification. An additional stage of amplification would unnecessarily complicate the circuit. So, thin film gages were selected for temperature sensors. The thin film gage has the advantage of a large resistance change for a modest temperature change. The gage is usually less than one micron thick and can be considered as part of the surface.

First attempts to construct thin film gages were based on the work of Vidal[10]. A substrate was made by casting Corning No. 7050 glass in the shape of a bead around a parallel pair of Kovar wires. The cast bead was oval-shaped, about one inch long and about 3/8 inches thick. The bead was cut in half along a plane normal to the wires, yielding two substrates per bead. The flat surface was then fire-polished and set aside to age. A zig-zag film of Platinum Bright Paint (Hanovia 05-X) was applied with a straight pen to the fire-polished surface between the two Kovar terminals.

The entire bead was baked in an oven raised slowly to 600°C over a one hour period until the Platinum solution had decomposed, leaving a bright, thin film of Platinum metal bonded to the glass. The bond derives its strength from the fact that the glass substrate has been brought to the softening point during baking. The bead was then removed from the oven and allowed to cool in air. The resistance of the films becomes stable after a week of aging and has a value somewhere between 1000 and 2000 ohms. Fig. 1 shows a sample of such a film. Fig. 2 illustrates a typical temperature-resistance calibration curve for this gage.

Unfortunately, a year's experience with telemeters using this particular gage showed that the gage consistently failed in flight. There was no conclusive way to determine the cause of failure but stresses in the glass bead were suspected. A new substrate made of Corning Pyroceram No. 9606 was tried. Pyroceram is a dense refractory material used in the making of cooking ware. Although Pyroceram was difficult to polish, a thin film could be applied to it after some mechanical polishing. There seemed to be fewer failures with the Pyroceram backed gage than with the glass substrate.

Sensors made of thin platinum films require a rigid non-conductor as a substrate. Another technique for applying thin films which may be used on metallic oxides is the cathodic sputtering of films in vacuum. Excellent bonds can be obtained between film and substrate by this process.[11,12] Cathodic sputtering has been used to make satisfactory high "g" temperature sensors by AEDC.[13] The quality of the bond depends on the high temperatures produced by ion bombardment during the sputtering process.

Circuitry. Fig. 3 shows the circuit diagram of a complete temperature telemeter consisting of sub-carrier oscillator, in-flight calibrator and carrier oscillator. The sub-carrier oscillator is a free-running multivibrator with capacitive coupling feedback. In one of the coupling loops, the capacitor is in parallel with the sensor. Thus, the frequency of operation of the sub-carrier is dependent on the resistance of the sensor. The nominal frequency of the sub-carrier oscillator is 30kc with a 1000 ohm sensor in the circuit. An increase of 1000 ohms in the sensor produces a frequency change of about 30kc. A typical resistance versus frequency curve for the SCO is shown in Fig. 4. After a number of firings with this circuit, it was observed that permanent frequency shifts ranging from 1000 to 3000 cps occurred. A number of projectiles without sensors were fired to see whether this shift was more or less constant from one circuit to the next. It was found that the frequency change was unpredictable. Some device which would furnish a reference frequency in flight would have to be included in the circuit. This would give an indication of how great a shift of SCO frequency occurred on any particular shot. An in-flight calibrator was designed which would permit periodic sampling of first the sensor resistance and then some internal and presumably unchanging impedance called the reference frequency. It was assumed that if a shift of SCO frequency occurred in flight, it could be measured by comparing the reference frequency during flight with the reference frequency before flight. The percent change in reference frequency could then be applied to the data as a correction factor, provided the changes took place over the linear portion of the calibration curve. The in-flight calibrator is another free-running multivibrator with a duty cycle of two milliseconds and is coupled to a transistor made to act as a swtich. This electronic switch is connected directly across the sensor and is biased near cutoff. A complete cycle of operation would be as follows: During the first half cycle of the free-running calibrator, the base of the transistor switch is held below cutoff and the transistor does not conduct. It becomes, in effect, an open circuit. In this condition, the SCO sees effectively just the sensor in the circuit. On the next half cycle of the calibrator, the base of the switching transistor is raised above cutoff and the transistor conducts. This condition effectively short circuits the sensor and the SCO sees only a short circuit where previously it had seen the sensor. The frequency of the SCO in this condition is called the reference frequency. Fig. 5 shows a typical oscilloscope trace of both the data and the reference frequency of the SCO. The in-flight calibrator has been very valuable not only in the reduction of data, but also in the analysis of sensor failure.

The nominal frequency of the radio frequency oscillator is about 70mc and was chosen at that value since at the time it was at the upper limit of operation of most transistors. The subcarrier signal is fed into the base of a 2N502 transistor by capacitive coupling and the signal frequency modulates the 70mc carrier. The carrier oscillator is not crystal controlled since it was found that crystals could not be internally potted. This has been the most successful circuit to date. The radiated power is about 200 microwatts.

Mechanical Construction. In the actual construction of the telemeter, the layout and orientation of parts is important. Fig 6 shows the components of the telemeter and Fig. 7 shows a completely assembled and potted projectile. The projectile shape chosen for temperature telemetering was a reentry vehicle, the GE type 3.1 design. This projectile is a high drag shape and is shown in Fig. 8

with its sabot. This model measured about three inches in diameter and had ample space for the electronic circuitry. Although space was not a major problem in this telemeter, every precatuion was taken to keep the electronics as small as possible, both from the point of view of minimizing the effect of acceleration and for the experience in miniaturization which would prove useful in future designs. The antenna was designed to be a spiral helix in order to get as close as possible to the conical rear surface of the projectile. The windscreen was made of nickel plated steel.

Acceleration Sensing Telemeter

Sensor. The results of the CARDE high "g" program[14,15] were studied and this experience was used in the consideration of acceleration sensors. The Columbia Research Corporation Model 512 accelerometer was chosen. The Model 512 is a piezoelectric crystal mounted in a stainless steel casing. An acceleration imposed on the sensor results in a signal from the crystal proportional to the magnitude of the acceleration. The piezo crystal is a high impedance device and is customarily used to measure varying acceleration. The crystal will measure constant acceleration when coupled to the input of a very high impedance circuit such as a cathode follower. Because the accelerations to be measured by this crystal would be changing with time and an a.c. signal would be produced, a moderately high impedance circuit was developed. Millivolt signals were expected over a frequency band from 5 - 100 cps. The sensor is mounted with its sensitive axis in a plane normal to the trajectory of the projectile and at some distance removed from the center of gravity. In such a location and orientation, the sensor will furnish in-flight data on the frequency and amplitude of oscillations of the shell about its center of gravity and on the damping of such oscillations.

Circuitry. The first circuit developed consisted simply of a Darlington connection to act as an impedance matching device between the crystal and the low impedance 70mc oscillator. The oscillator was frequency modulated directly by the varying output of the crystal without recourse to a subcarrier oscillator. Fig. 9 shows this circuit schematically and it is based on the original CARDE circuit except for different values and transistors. The current circuit employs a subcarrier oscillator and is shown in Fig. 10. The input here is also a Darlington connection formed by transistors Q_1 and Q_2. Q_3 is a pre-amplifier to boost the low level signal from the crystal to an amplitude which can be used to operate Q_4. Q_4 is used as a voltage controlled impedance to frequency modulate the subcarrier oscillator Q_5 and Q_6. Q_7 is the 70mc carrier oscillator. The input impedance of the Darlington connection is nominally 5 megohms and the pre-amplifier is set for an input swing of 0 - 10 millivolts.

Mechanical Construction. An experimental reentry vehicle (RVX) shape, consisting of a cone-cylinder-flare configuration, was chosen for the acceleration sensing telemeter, and is shown in Fig. 11. Ballast had to be added to the nose section in order to maintain a forward center of gravity. A first attempt to construct this shell involved the use of epoxy resin but the resulting shell burned freely and broke up at high accelerations. The final construction technique used woven fiberglass and provided a strong vehicle unaffected by the high temperatures produced in flight.

Vertical Probe Telemeter

Both BRL and McGill University have been using conventional or slightly modified artillery at high angles of elevation in order to launch research probes into the upper atmosphere.[16] BRL has fired a number of such probes in the last two years.[17] Altitudes exceeding 250,000 feet have been achieved. After the high altitude capability of the BRL guns had been demonstrated, it became necessary to instrument the vertical probe vehicles to obtain data on the upper atmosphere. The high "g" program was expanded to include the development of a high power transmitter with associated circuitry to transmit data from high altitudes back to ground receiving stations. In the vertical probe guns, much lower "g" loads could be anticipated than in horizontal high velocity firings. Nominally, the BRL 5-inch gun would produce no more than 60,000 "g" for a muzzle velocity of about 5500 feet per second. The McGill 16-inch gun at Barbados has even lower "g" loads of approximately 10,000 "g".

Sensors. At the outset of the vertical probe program, no sensors for the measurement of upper atmosphere parameters were avilable. It was decided that interior temperatures of the shell would be useful data and would provide the program with a measurement objective. Later in the program, attention was given to the development of sensors to measure skin temperatures, free air temperatures, electron densities, radiation and other measureables of the atmosphere. In order to monitor interior shell temperatures, a bead thermistor made by Gulton Industries (Type 41CB1) was chosen. The thermistor had a nominal resistance of 10,000 ohms. It was placed in the instrument compartment of the shell and provided data which could be used to determine whether the instrument compartment ever reached significantly high temperatures.

Circuitry. Work was done on circuit development both at Harry Diamond Laboratories (HDL) and at Airborne Instruments Laboratory (AIL) under separate contracts. The initial HDL circuit is shown in Fig. 12. The carrier oscillator developed for the temperature telemeter was improved and a power amplifier was added to give increased power output. The subcarrier was made from a uni-junction transistor which acts as an audio oscillator at a nominal value of 30kc. This circuit is described by Stutzke.[18] The power amplifier was capable of 150 milliwatts into a 50 ohm load at 70mc. Due to poor antenna efficiency, only about 20 milliwatts of radiated power (with respect to a standard dipole) was achieved. In order to boost the radiated power, a second power amplifier was added and the resulting circuit is shown in Fig. 13. This circuit was capable of delivering 500 milliwatts into a 50 ohm load and the radiated power increased to 100 milliwatts. A number of the second variety circuits were built and tested for radiated power. The variation in power output from one measurement to the next was so marked that this scheme of simply adding power amplifiers was abandoned in favor of using the higher power transistors which had then become available. Work is currently in process of a 250mc transmitter capable of delivering 2 watts into a 50 ohm load. Fig. 14a shows the components of the telemeter before and after potting. Fig. 14b shows the complete probe.

Antenna. It was decided to use the body of the shell as an antenna. The nose cone is separated from the body by a fiberglass washer, thus creating an asymmetrical dipole. The output of the 70mc power amplifier is developed across the gap created by the washer. A loading coil is placed in the antenna coupling line in order to match impedances between amplifier and antenna. A tuning slug was included in the coil to provide a capability for fine tuning the impedance match. The radiation pattern was essentially dipole. Despite the use of a loading coil, the efficiency remained poor. This type of antenna is problematical for gun launched projectiles since small changes in the dimensions of the gap or changes in the dielectric filling the gap seriously affect the power transmitted. Such changes are not unreasonable when gun launch accelerations are considered. The small dimensions of the present vertical probe body (2 1/2 inches in diameter) preclude the use of other types of antenna at 70mc.

The Ground Station

A ground receiving and recording station was set up close by the horizontal range. The station is shown schematically in Fig. 15, and consists of a series of antennas feeding into FM receivers which in turn are coupled to a magnetic tape recorder. A long wire transmission line antenna was tried with the horizontal firings, but did not prove as satisfactory as a series of dipoles spaced along the flight path. Nems Clarke type 1501A FM receivers were used to pick up the signal from the antennas and demodulate the FM carrier. The receiver video outputs were connected to an Ampex FR100, direct record, magnetic tape machine and the FM subcarrier signal was recorded directly on tape. In addition to the data frequency, a standard frequency from a signal generator, a time zero pulse and a timing signal were recorded on separate channels. The standard frequency was needed for data reduction and to obviate the need for knowing the tape wow and flutter accurately. The time zero pulse was obtained from the gun firing circuit and gave an absolute reference point in time. The 1501A receiver had a 300kc bandwidth purposely chosen so large because of uncertainties in the frequency stability of the 70mc oscillator. More recently, some Nems Clarke model 1037A receivers have been obtained for the vertical probe ground station and these receivers have excellent sensitivity in addition to variable bandwidth. During a firing, the Ampex tape recorder is run at 60 ips and later played back at 1 7/8 ips into an oscillograph recorder. The final graphic recording contains the data frequency, the standard frequency and the time zero and timing channels. Data is reduced by comparing the data frequency with the standard frequency.

The ground equipment for monitoring vertical shots was essentially the same as that for horizontal firings. High gain Yagi antennas were used in the 70mc band and helices will be used at 250mc.

RESULTS

Temperature Telemeter

A number of firings were accomplished during the development program of the past three years. Each model fired was a prototype, and singular rather than statistical data are available. After each prototype firings, results were analyzed and improvements included in subsequent models.

The first projectiles fired contained subcarrier oscillators and radio frequency oscillators, without sensors on board. These tests consisted of simple observations of the in-flight subcarrier frequency to determine circuit behavior and stability. After these initial tests, sensors were included and data was sought. Table I gives a summary of the firing program. Table II provides a commentary on Table I, indicating probable causes of failure. A total of twenty-nine telemetering projectiles were delivered by HDL during the program. Five of these became inoperative on the shelf, probably because of battery or transistor failure. These five were early models and the shelf life has been extended in later models. Twenty-four models were fired in the Transonic Range. Of these, twenty carrier oscillators survived and signals were picked up by the FM receivers. Nineteen subcarrier oscillators functioned and the signals were recorded on tape. Accelerations in the gun ranged from 167,000 to 288,000 "g" with velocities from 5800 to 8300 feet per second. In five cases, no signals were recorded and of these, four models hit the protective blast shield in front of the range. The remaining failure occurred after the model had been turned on for an hour and a half in subzero weather. (It was jammed in the gun.) Of the fifteen projectiles with sensors on board, only two gave reasonable data. Nine of the sensors broke on launch and the four other circuits drifted considerably during flight. The final shot of the program (SC 19) gave excellent temperature data. The results of this shot are shown in Fig. 16 in the form of a temperature-time history. Unfortunately, the channel containing the first down range antenna was excessively noisy and early flight data could not be obtained. Thus, the data record begins at T + 80 millisec. The data points are compared with a curve obtained from an empirical relation of AVCO.[19] A discussion of the theoretical considerations leading to the use of the AVCO empirical relation for heat transfer is presented in the Appendix. The two curves, experimental and quasi-theoretical, agree quite well in slope and are within 15% in amplitude.

Fig. 17 shows a smear photograph of a telemetering projectile in flight. The sabot has separated and the fragments are traveling symmetrically some distance behind the model. At higher velocities, the sabot fragments will burn, as seen in Fig. 18. Good sabot separation helps insure that the model will enter the range and not hit the blast-protecting shield in front of the range. At extremely high velocities, the steel windscreen itself would become hot enough to glow.

Fig. 19 shows a subcarrier signal from one of the early prototypes in flight. Both pre-shot and in-flight signals are shown. As seen in the figure, the early model subcarrier signals suffered substantial distortion after launch. By contrast, Fig. 20 shows the subcarrier signal from a later model during flight. The signal shown here is free from distortion and poise. Finally, Fig. 21 shows an oscillogram of the in-flight calibrator in operation during a shot. Two distinct frequencies of the subcarrier are observed.

It has been pointed out that the 3.1 vehicle is a high drag shape. Often after a firing it was possible to walk downrange and pick up the telemeter which was lying on the ground. In many cases, it was still transmitting.

Acceleration Sensing Telemeter

The RVX shape chosen for acceleration telemetry was built up as an all plastic model in order to transmit from it. A number of dummy models were fabricated from Epoxy/LP-3 mix and flown in the range. These projectiles invariably broke up on leaving the gun. The next approach was to construct several different types of fiberglass bodies. Only the roven fiberglass mentioned earlier survived. Several of these roven fiberglass rounds were tried out of the 240-176-76mm light gas gun and they performed satisfactorily. In the meantime, a number of active circuits were developed and flown with no results. Work still continues on the circuit development. Table III summarizes the results of firing acceleration sensing telemeters.

Fig. 22 is a photograph of the breakup of an all Epoxy/LP-3 dummy model. The ballast slug can be clearly seen flying by itself. Fig. 23 shows the flights of three different types of fiberglass models.

Vertical Probe Telemetry

The results of vertical firings of the same telemetry probe have been reported by Marks and Boyer.[17] The only successful firing of this HDL package has been in a horizontal test through the Transonic Range. The vertical firings involved telemeters of substantially lower output than desired and no signals were picked up.*

CONCLUSIONS

It has been demonstrated that functional electronic circuits can be built and hardened to survive the high accelerations experienced in hypervelocity gun launches. Data has been obtained from high velocity firings. Improvements in stability, power and accuracy are well within the capabilities of the state of the art. The area requiring greatest effort is sensor development. With slight

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* In January 1964, 250mc telemetery units built by HDL and Computing Devices of Canada (CDC) were fired from the HARP-McGill 16 inch gun. Two of the CDC units were successfully launched and transmitted some signals. In Marhc 1964 HDL built 250mc telemeters were successfully launched from the HARP 5 inch gun and transmitted good signals.

improvements in circuitry and with improved sensors, it is felt that the high "g" telemeter will become a valuable instrument for use in reentry experiments in the BRL hypervelocity ranges.

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W. H. Mermagen

W. H. MERMAGEN

REFERENCES

1. Braun, W. The Free Flight Aerodynamics Range. Ballistic Research Laboratories Report No. 1048, July 1958.

2. Rogers, W. K. The Transonic Free Flight Range. Ballistic Research Laborateries Report No. 1044, June 1958.

3. Bull, G. V. Re-entry Studies in Free Flight Ranges, Canadian Armament Research and Development Establishment, Valcartier, Quebec. I.A.S. Paper No. 59-143, The 7th Anglo-American Aeronautical Conference, October 5-7, 1959.

4. Kingery, M. K., Choate, R.H. and Young. R. P. Progress Report on Development of Telemetry for a Hypervelocity Range. Arnold Engineering and Development Center Report No. AEDC-TN-60-214, ASTIA Document No. AD-248019, December 1960.

5. Clemens, P. L. Bibliography: Radio Telemetry to Survive High Accelerations. Arnold Engineering and Development Center Report No. AEDC-TDR-63-36, February 1963.

6. Rosenberg, G., Tomasello, J. C. and Gieseler, W. L. First Interim Report - DOFL High-G Telemetry System. Diamond Ordnance Fuze Laboratories Report No. TR-341, May 1960.

7. Kingery, M. K. Preliminary Development of Telemetry for Aeroballistic Ranges. Arnold Engineering and Development Center Report No. AEDC-TN-59-7, ASTIA Document No. AD-208692, February 1959.

8. Letarte, M. A Miniaturized Telemetry System for Guns and Rocket Firings - Status Progress. Canadian Armament Research and Development Establishment, Valcartier, Quebec, Technical Memorandum 235/59, ASTIA Document No. AD-225807, July 1959.

9. Thiokol Chemical Corporation. Liquid Polymer/Epoxy Resin Systems.

10. Vidal, R. J. Model Instrumentation Techniques for Heat Transfer and Force Measurements in a Hypersonic Shock Tunnel. Cornell Aeronautical Laboratories Report No. AD-917-A-1, February 1956.

11. Belser, R. B., and Hicklin, W. H. Simple Rapid Sputtering Apparatus. Review of Scientific Instruments, Vol. 27, No. 5, p. 293, May 1956.

12. Holland, L. Vacuum Deposition of Thin Films. New York. John Wiley & Sons, Inc., 1961.

13. Private communication.

14. Letarte, M. and Moir, L. E. A High "g" Telemetry System for Gun and Rocket Firing. Canadian Armament Research and Development Establishment, Valcartier, Quebec. Report No. TM 351/60, ASTIA Document No. AD-244158, August 1960.

REFERENCES

15. Letarte, M. and Moir, L. E. The Application of Telemetry to Aeroballistic Range Studies. Canadian Armament Research and Development Establishment, Valcartier, Quebec. Proceedings of the Symposium on Aeroballistic Ranges - CARDE, June 1961.

16. Bull, G. V. and Murphy, C. H. Gun-launched Missiles for Upper Atmosphere Research. AIAA Reprint 64-18, January 1964.

17. Marks, S. T. and Boyer, E. D. A Second Test of an Upper Atmospheric Gun Probe System. Ballistic Research Laboratories Memorandum Report No. 1464, April 1963.

18. Stutzke, R. Transistorized Preamplifier and SCO for Piezoelectric Accelerometer. Harry Diamond Laboratories Report No. R530-63-1, 1963.

19. Detro, R. W. and Hidalgo, H. Generalized Heat Transfer Formulae and Graphs. AVCO-Everett Research Report No. 72, March 1960.

20. Boison, J. C. and Curtiss H. A. An Experimental Investigation of Blunt Body Stagnation Point Velocity Gradient. American Rocket Society Journal, Vol. 29, No. 2, pp. 130-135, February 1959.

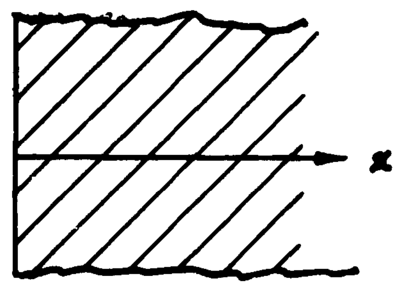
APPENDIX

Quasi-theoretical calculations of expected in-flight nose tip temperatures were made in order to determine whether the temperature data obtained from projectile SC 19 were reasonable or not. These calculations proceeded from certain simplifying assumptions regarding the sensor substrate and a suitable solution of the heat equation at the boundary.

The glass bead substrate was considered as a homogeneous semi-infinite solid with coefficient of thermal conductivity k. The heat conduction process is then, one dimensional and the heat equation is written

$$\frac{\partial T}{\partial t}(x,t) = k \frac{\partial^2 T}{\partial x^2}(x,t) \qquad (1)$$

where x is the distance into the solid from the front surface, T(x,t) is the temperature along x at any time t, and $k = \frac{K}{C}$ where K is the thermal diffusivity and C is the specific heat.



The general solution of the heat equation for steady state conditions is

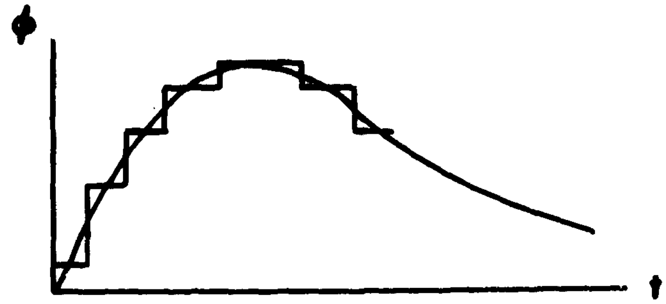
$$T\ (x,t) = \frac{\phi_o}{K}\left[2\sqrt{\frac{kt}{\pi}}\ e^{\frac{-x^2}{4kt}} - x\ \mathrm{erfc}\left(\frac{x}{2\sqrt{kt}}\right)\right], \qquad (2)$$

where ϕ_o is a constant representing the heat transferred per unit surface area and unit time, and where erfc is the complementary error function defined by

$$\mathrm{erfc}\ (\lambda) = \frac{2}{\sqrt{\pi}}\int_{\lambda}^{\infty} e^{-y^2}\ dy.$$

In the case of a body moving with variable velocity, the heat input is no longer constant ($\phi_o \neq$ constant) and the above solution (2) is no longer exact.

Let us approximate the case of varying heat input with a heat input which is piecewise constant over short enough time intervals to be a reasonable approximation of the true input function.



Then, the complete solution to the heat equation will be a superposition of solutions obtained from successive different constant heat inputs. Let us examine the details of this approximation. Define the initial temperature for the solid as T_o and define a function T_1 for the interval $0 < t < t_1$ so that

$$T_1\ (x,o) = T_o\ . \tag{3}$$

For a semi-infinite solid

$$\lim_{x \to \infty} T_1\ (x,t) = T_o\ , \tag{4}$$

or, the temperature of the solid at great distances from the surface is the initial temperature for all times.
Write that

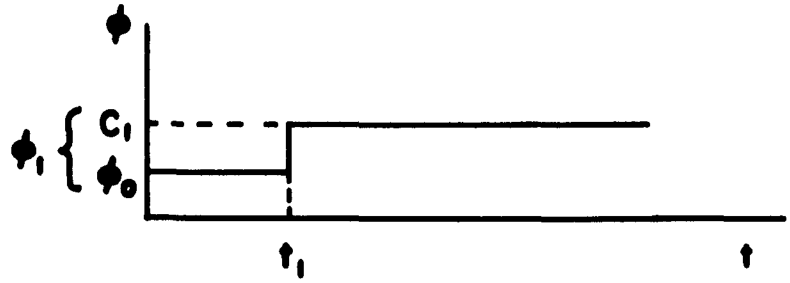
$$\phi_o = k \left.\frac{\partial T_1(x,t)}{\partial x}\right|_{x = o}\ , \tag{5}$$

which states that the heat flux per unit area and time during the interval $0 < t < t_1$ is constant at the free surface of the solid.
Thus, for $x = o$

$$T_1\ (o,t) = 2\,\frac{\phi_o}{K}\,\sqrt{\frac{\kappa t}{\pi}} + T_o\ . \tag{6}$$

Consider now the next interval of time $t_1 < t < t_2$. Define a function $T\ (x,t)$ so that

$$k \left. \frac{\partial T(x,t)}{\partial x} \right|_{x=o} = \phi_o + \phi_1 = C_1 \ . \tag{7}$$



The new function $T\ (x,t)$ will in general be different from $T\ (x,t)$ and takes into account the heat input history. This new function must also decay to T_o at large x:

$$\lim_{x \to \infty} T\ (x,t) = T_o \ . \tag{8}$$

Now, define

$$T = (T_1 + T_o) + T_2 \ , \tag{9}$$

where

$$\begin{aligned} T_1 &= T_1\ (x,t) \\ T_2 &= T_2\ (x,\ t-t_1) \ . \end{aligned} \tag{10}$$

Then,

$$k \left. \frac{\partial T(x,t)}{\partial x} \right|_{x=o} = k \left[\left. \frac{\partial T_1(x,t)}{\partial x} \right|_{x=o} + \left. \frac{\partial}{\partial x} T_2(x,t-t_1) \right|_{x=o} \right] ,$$

or, by comparison with (7)

$$k \left. \frac{\partial T_2(x,t-t_1)}{\partial x} \right|_{x=o} = \phi_1 \ . \tag{11}$$

Define

$$\begin{aligned}
&(a) \qquad T_2(x,\ t-t_1) = 0\ , \quad \text{for } t-t_1 < 0\ , \\
&(b) \qquad T_2(o,o) = T_1\ , \\
&(c) \qquad \lim_{x \to \infty} T_2(x,\ t-t_1) = T_o\ .
\end{aligned} \tag{12}$$

Then,

$$T_2(o,\ t-t_1) = 2\,\frac{\phi_1}{K}\sqrt{\frac{k}{\pi}}\ \sqrt{t-t_1}\ ,$$

and T_2 is also a solution of the heat equation at the boundary $x = 0$. Hence

$$T = T_1 + T_2 + T_o$$

is indeed a solution of (1).

Generalizing, we write

$$T = \sum_{i=o}^{n} T_i\ , \tag{13}$$

and

$$C_n = \sum_{i=o}^{n} \phi_i = \sum_{i=o}^{n-1} \phi_i + \phi_n \tag{14}$$

or,

$$\phi_n = C_n - \sum_{i=o}^{n-1} \phi_i\ .$$

Thus,

$$T = \frac{2}{K}\sqrt{\frac{k}{\pi}} \sum_{n=o} \phi_n\ \sqrt{t-t_{n-1}} + T_o,$$

and, since

$$\phi_n = C_n - \sum_{i=0}^{n-1} \phi_i,$$

have

$$\phi_0 = \phi_0,$$
$$\phi_1 = C_1 - \phi_0,$$
$$\phi_2 = C_2 - \phi_1 - \phi_1 = C_2 - C_1,$$
$$\phi_n = C_n - C_{n-1}.$$

Finally,

$$T = \frac{2}{K}\sqrt{\frac{k}{\pi}} \sum_{n=0} (C_n - C_{n-1}) \sqrt{t - t_{n-1}} \tag{15}$$

becomes the formula for computing the boundary (nose tip) temperature at any time t. If K and k are known for the particular substrate material, only ϕ need be specified to perform the calculation. An empirical formula for ϕ at the stagnation point of a sphere was obtained by R. W. Detra and H. Hidalgo of AVCO[19] and was applied to this calculation:

$$\phi\sqrt{R} = 865\left(\frac{V}{10^4}\right)^{3.15}\sqrt{\frac{\rho_\infty}{\rho_{sl}}}\ \frac{H_s - h_w}{H_s - h_{w_{300}}} \tag{16}$$

where

R	=	nose radius of a sphere, ft.
V	=	in flight velocity, ft./sec.
ρ_∞	=	mass density of the free stream air
ρ_{sl}	=	mass density of air at sea level
H_s	=	total enthalpy
h_w	=	enthalpy of the nose wall
$h_{w_{300}}$	=	initial enthalpy of the nose wall

Since the nose tip is flat and not spherical, an effective nose radius, R_{eff}, was used. R_{eff} was taken from an article by J. C. Boison and H. A. Curtiss of AVCO[20] which accounts for the variation in bluntness from a sphere. For this nose tip, $R_{eff} = 0.845$. For our calculation $\rho_{\infty} = \rho_{sl}$, and if an ideal gas was assumed,

$$\phi \sqrt{R_{eff}} = 865 \left(\frac{V}{10^4}\right)^{3.15} \frac{T_s - T_w}{T_s - T_{w_{300}}} \tag{17}$$

To begin the calculation, it was assumed that $T_w = T_{w_{300}}$ initially. ϕ_o was then calculated in (17) and used in (15) to give T^* over the initial time interval $t-t_1$. This T^* was then used in (17) as T_w to give a new ϕ_1 for the interval t_2-t_1. ϕ_o and ϕ_1 were then used to compute a new T^* for t_2-t_1. The calculation then proceeded in similar fashion through the entire flight history of the shot.

TABLE I

Model†	Type of Gage	Velocity (fps)	Acceleration ("g")	Transmitter	SCO	Gage	Data	Remarks (see Table II)
1E	No Gage*	6850	203,000	No	No	-	-	(1)
2E	No Gage*	6740	211,000	Yes	Yes	-	-	
3E	No Gage*	-	-	Yes	Yes	-	-	(2)
3E	No Gage*	6850	237,000	Yes	No	-	-	(3)
4E	No Gage*	?	201,000	Yes	Yes	-	-	(4)
5E	Quartz Substrate	7100	200,000	Yes	Yes	Yes	Yes	
7E	No Gage*	7700	252,000	Yes	Yes	-	-	
8E	Quartz Substrate	7850	213,000	Yes	Yes	Yes	No	(5)
9E	Quartz Substrate	7950	189,000	Yes	Yes	Yes	No	(5)
1EN	No Gage*	5831	210,000	Yes	Yes	-	-	
2EN	No Gage*	?	?	-	-	-	-	(6)
3EN	Quartz Substrate	?	246,000	-	-	-	-	(6)
4EN	Quartz Substrate	7150	197,000	Yes	Yes	No	No	(7)
5EN	No Gage*	7550	235,000	Yes	Yes	-	-	
6EN	Quartz Substrate	7650	226,000	Yes	Yes	Yes	No	(4)
SC1	Quartz Substrate	7170	288,000?	Yes	Yes	No	No	(7)
SC2	Quartz Substrate	8170	275,000?	Yes	Yes	No	No	(7)
SC4	Quartz Substrate	7670	285,000?	Yes	Yes	No	No	(7)
SC10	PyroC Substrate**	8300	230,000	Yes	Yes	No	No	(7,8)
SC11	PyroC Substrate**	7500	180,000	Yes	Yes	No	No	(7,8)
SC12	PyroC Substrate**	8000	210,000	Yes	Yes	No	No	(7,8)
SC14	PyroC Substrate**	6060	167,000	Yes	Yes	Yes	No	(7,8)
SC17	PyroC Substrate**	6380	184,000	Yes	Yes	No	No	(7,8)
SC18	PyroC Substrate**	6880	215,000	-	-	-	-	(6)
SC19	PyroC Substrate**	6410	206,000	Yes	Yes	Yes	Yes	(8)

* SCO and RFO circuits on board.
** Pyroceram was the substrate material.
? Means data uncertain or unavailable.
\- Means not applicable.
Yes Means success.
No Means failure.
† Model number code refers to telemetry package numbers assigned by HDL.

TABLE II

(1) The model jammed while being loaded into the gun. After an hour and a half in freezing weather, it was finally fired but did not function. Tests have shown that batteries become inoperative below 40°F.

(2) Only the shell primer functioned and generated sufficient gun chamber pressure to launch the model 340 feet into the range. The model was recovered and fired again.

(3) The second firing of the No. 3E round.

(4) The SCO signal was noisy and distorted during flight.

(5) Substantial drift of SCO frequency during flight. More than can be accounted for by temperature sensor changes alone.

(6) Bad launch from the gun. Model hit the blast-protecting shield in front of the range.

(7) Sensor open-circuited in flight.

(8) This model had an in-flight calibrator on board.

TABLE III

Round	Type	Velocity (fps)	Acceleration ("g")	Electronics	Remarks
6004	Epoxy Type A	*	161,000	-	Failed
6005	Epoxy Type A	*	92,000	-	Failed
6075	Epoxy Type B	*	170,000	-	Failed
6077	Epoxy Type B	*	153,000	-	Failed
6099	Fiberglass B	8000	161,000	-	Survived
6100	Fiberglass C	8200	160,000	-	Survived
6101	Fiberglass A	8200	158,000	-	Failed
6166	Fiberglass C	7400	143,000	-	Survived
6167	Fiberglass C	8000	203,000	-	Survived
6225	Fiberglass C	8000	183,000	Yes	Hit blast shield
6226	Fiberglass C	7600	172,000	Yes	Hit blast shield
6302	Fiberglass C	6850	135,000	Yes	No signal
4-19	Fiberglass A	6600	**	-	Failed
4-21	Fiberglass B	6400	**	-	Failed
4-22	Fiberglass C	6250	**	-	Survived

* Velocity could not be obtained since the projectile broke up on launch.

** These models were fired from the 240-176-76mm light gas gun. No chamber pressure data were available and "g" loads could not be computed.

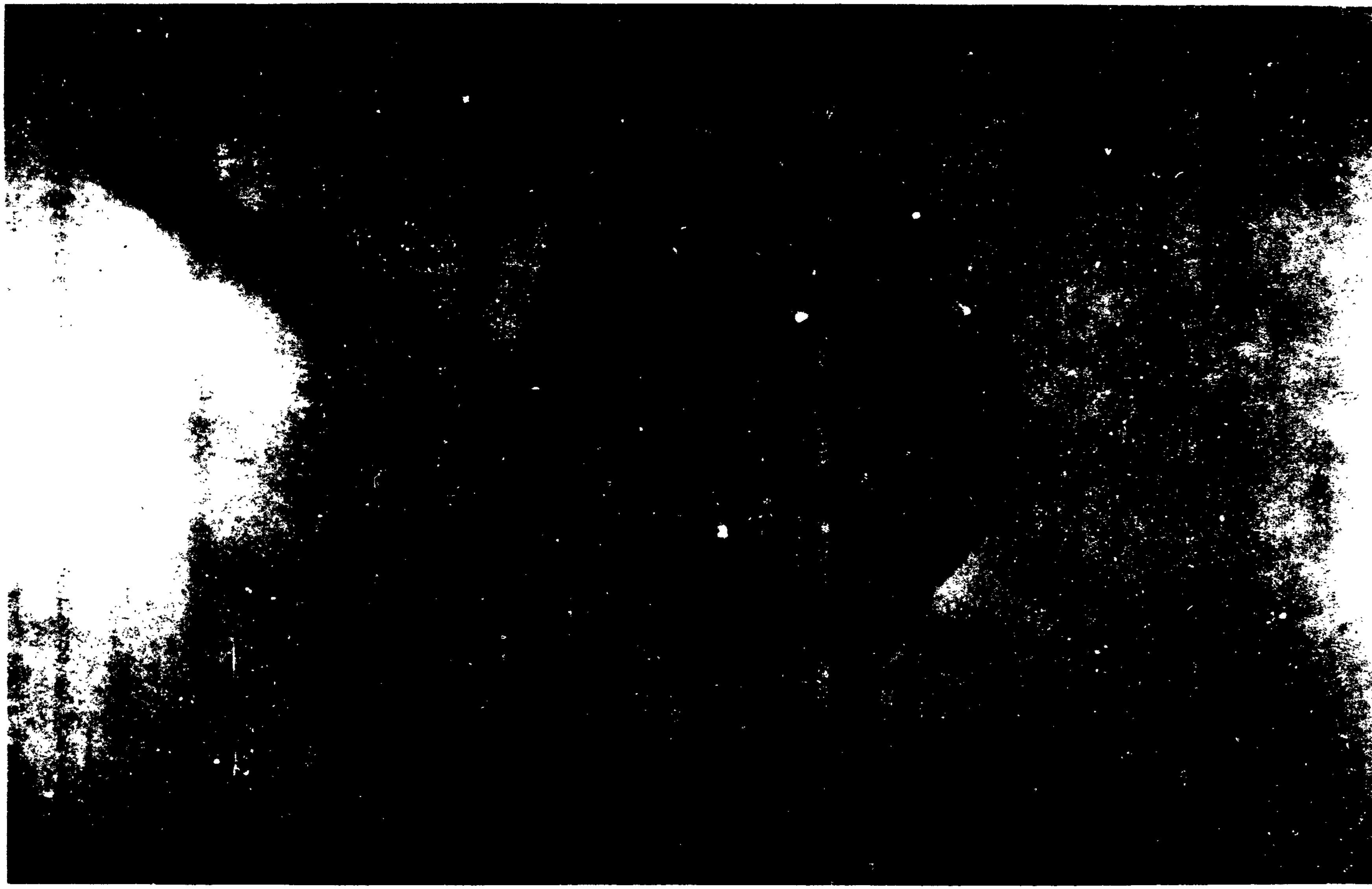


Fig. 1. A chemically deposited platinum thin film temperature sensor.

TYPICAL TEMPERATURE SENSOR CALIBRATIONS
PLATINUM FILM ON PYROCERAM

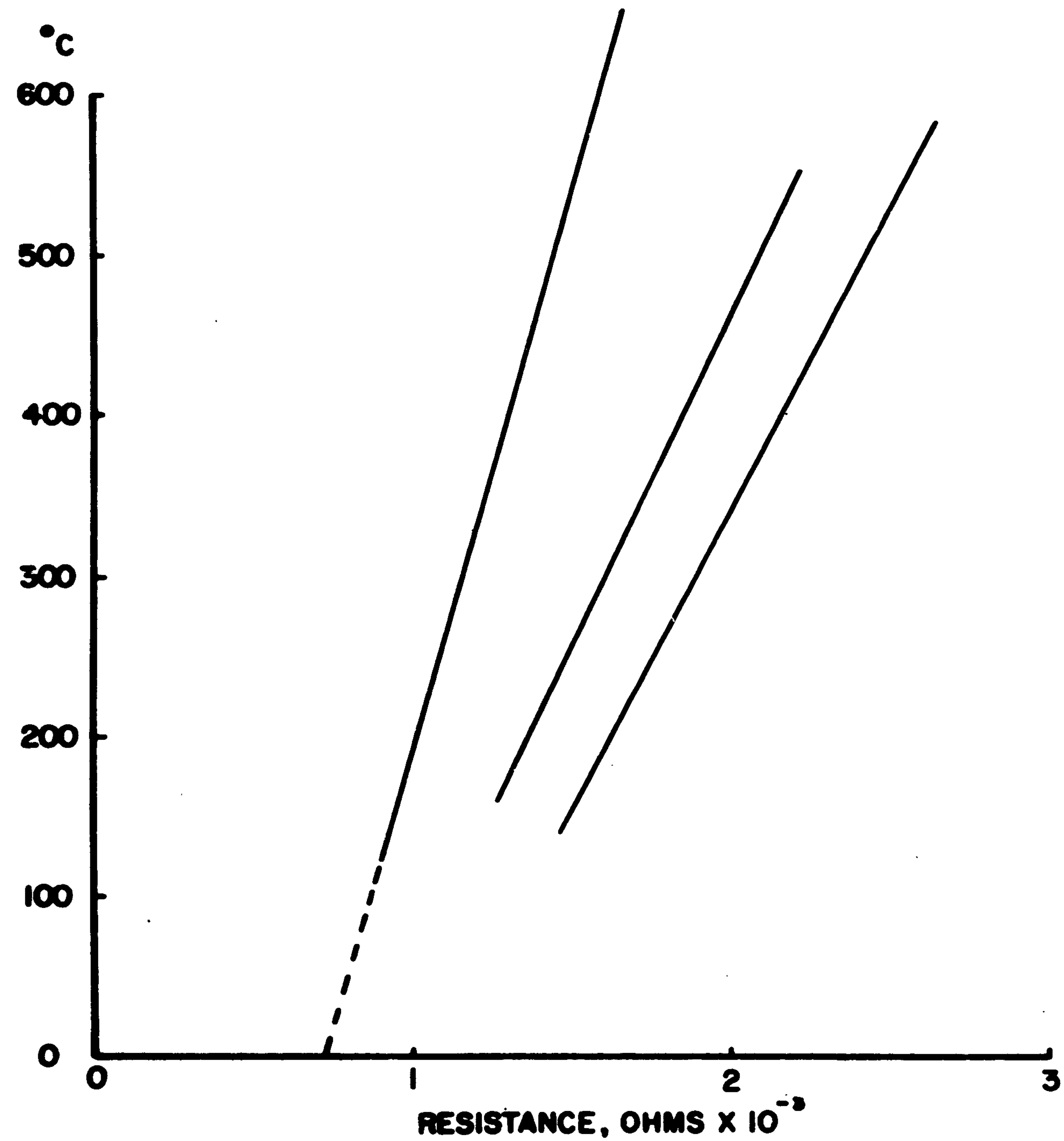


FIG. 2

CIRCUIT DIAGRAM - FM/FM TEMPERATURE TELEMETER

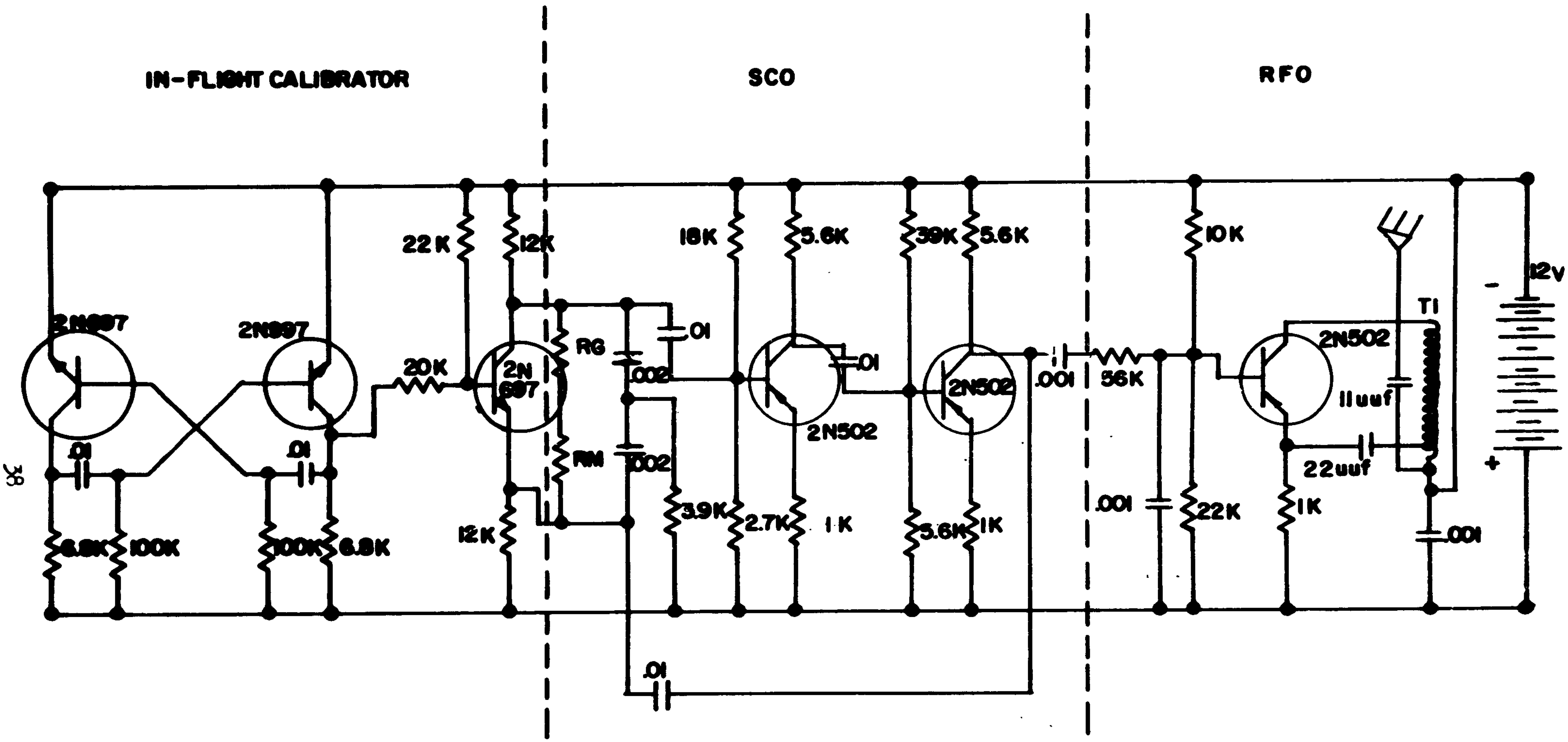


FIG. 3

TYPICAL SCO CALIBRATION CURVE

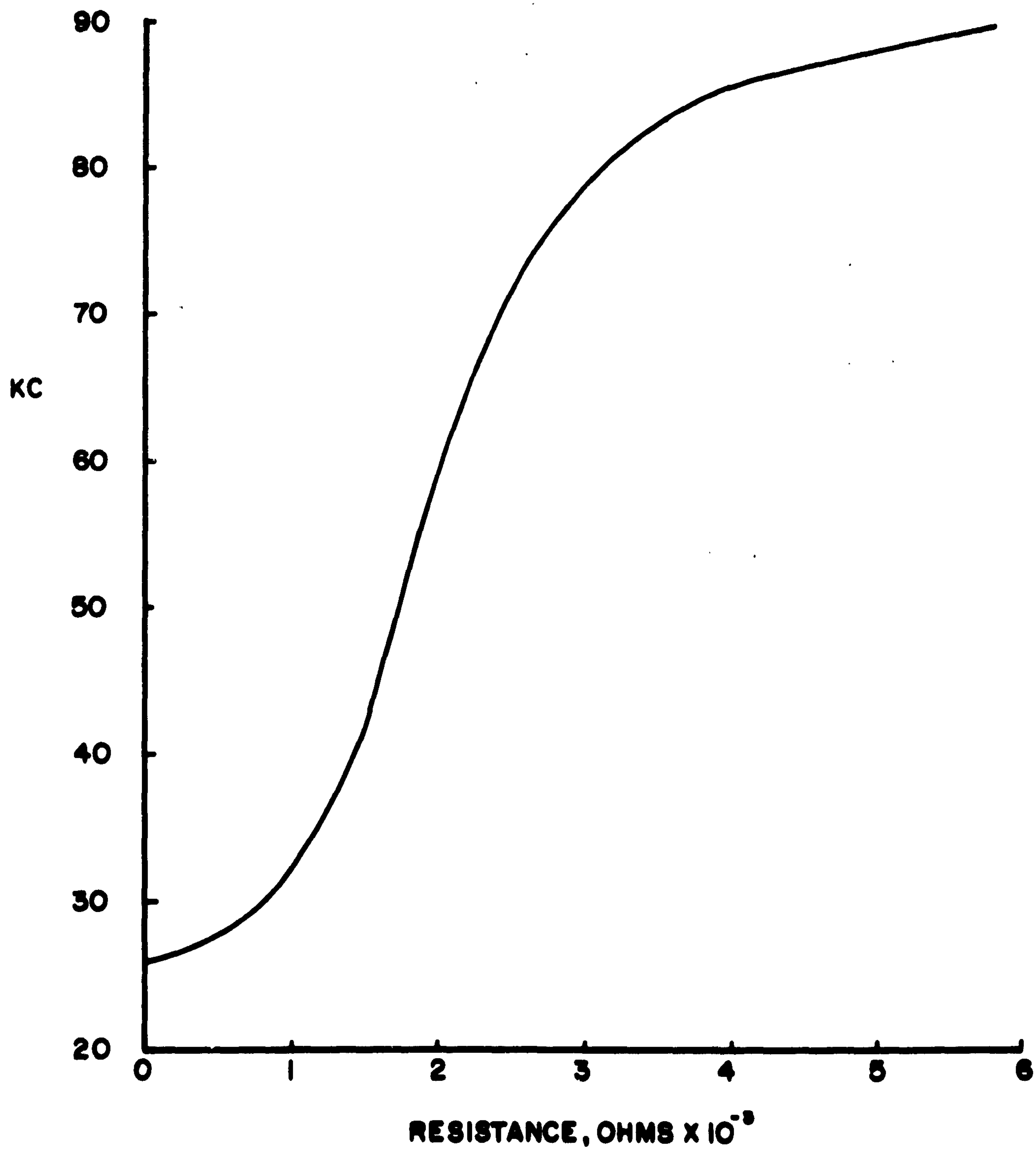


FIG. 4

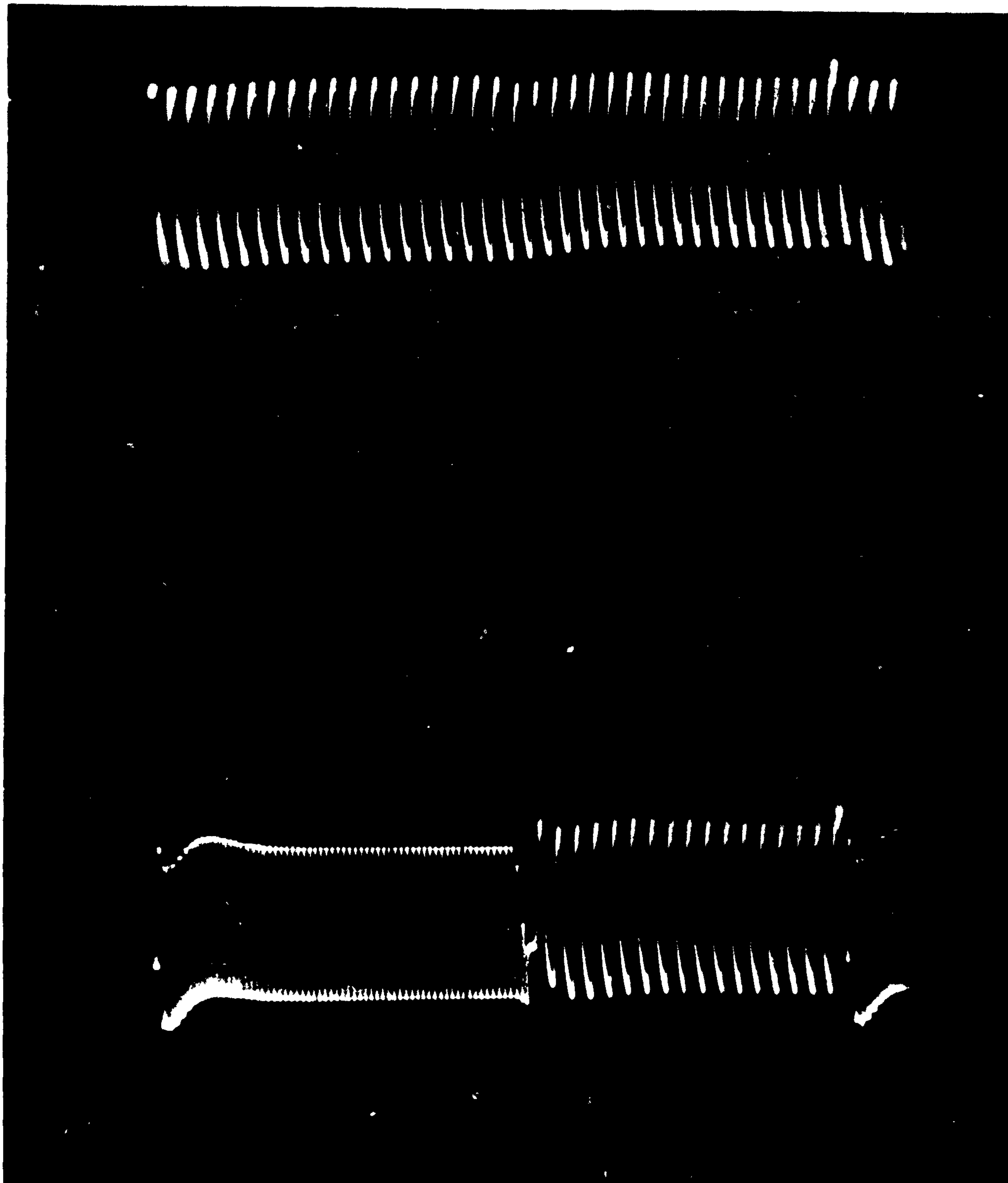


Fig. 5. The lower trace shows data and reference frequency with the sensor at ambient conditions. The upper trace shows the change of frequency produced by a change in the sensor.

Fig. 6. Components of the temperature sensing telemeter.

Fig. 7. Completely potted temperature sensing telemeter assembly.

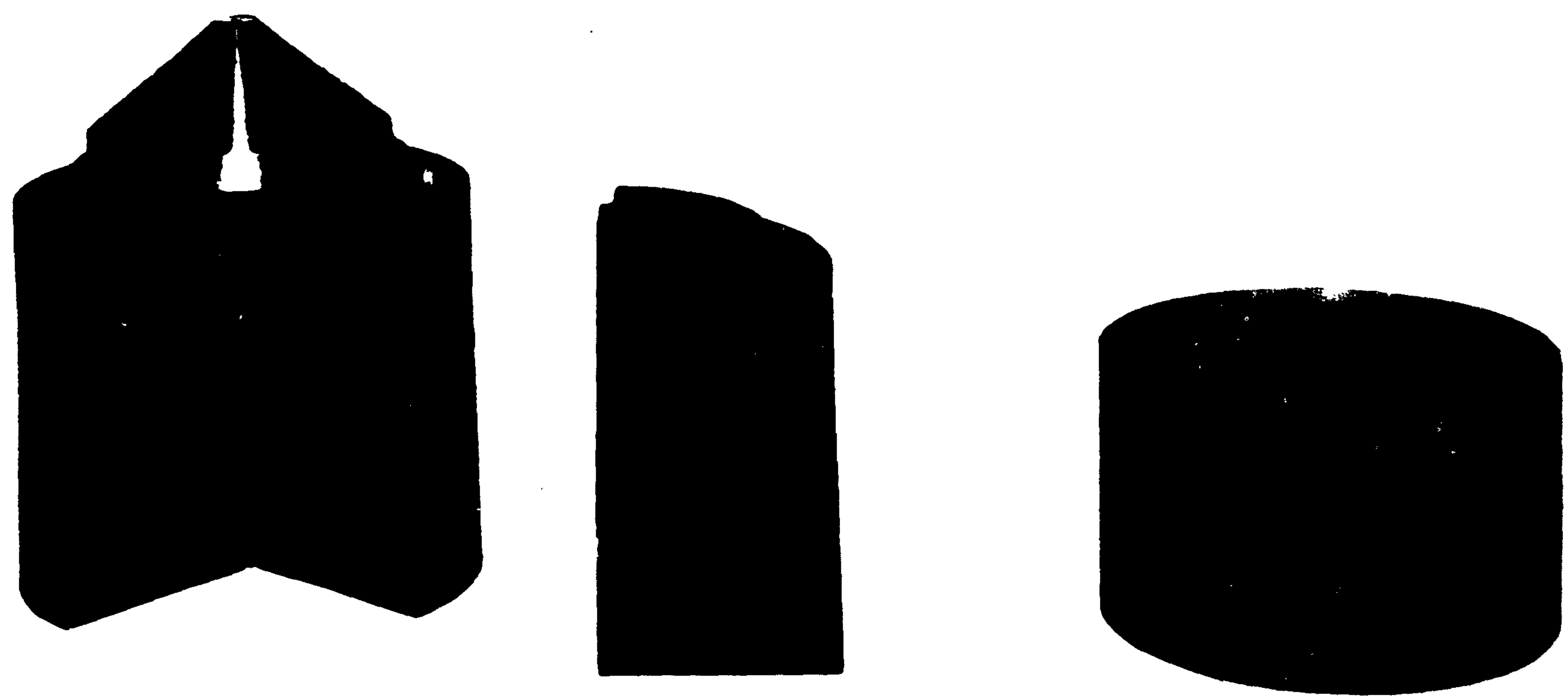


Fig. 8. Temperature telemeter with sabot.

ACCELEROMETER TELEMETER CIRCUIT–FM SYSTEM

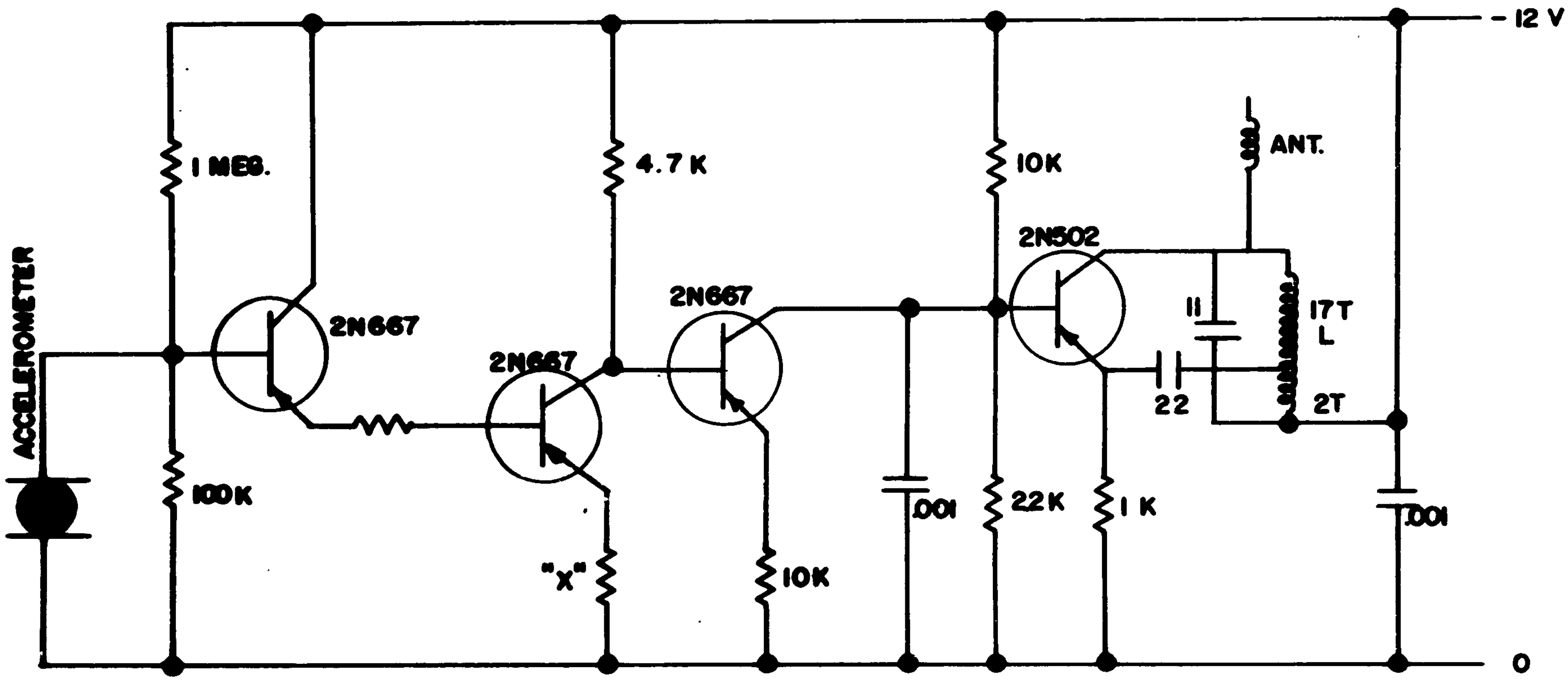


FIG. 9

ACCELEROMETER TELEMETER CIRCUIT–FM/FM SYSTEM

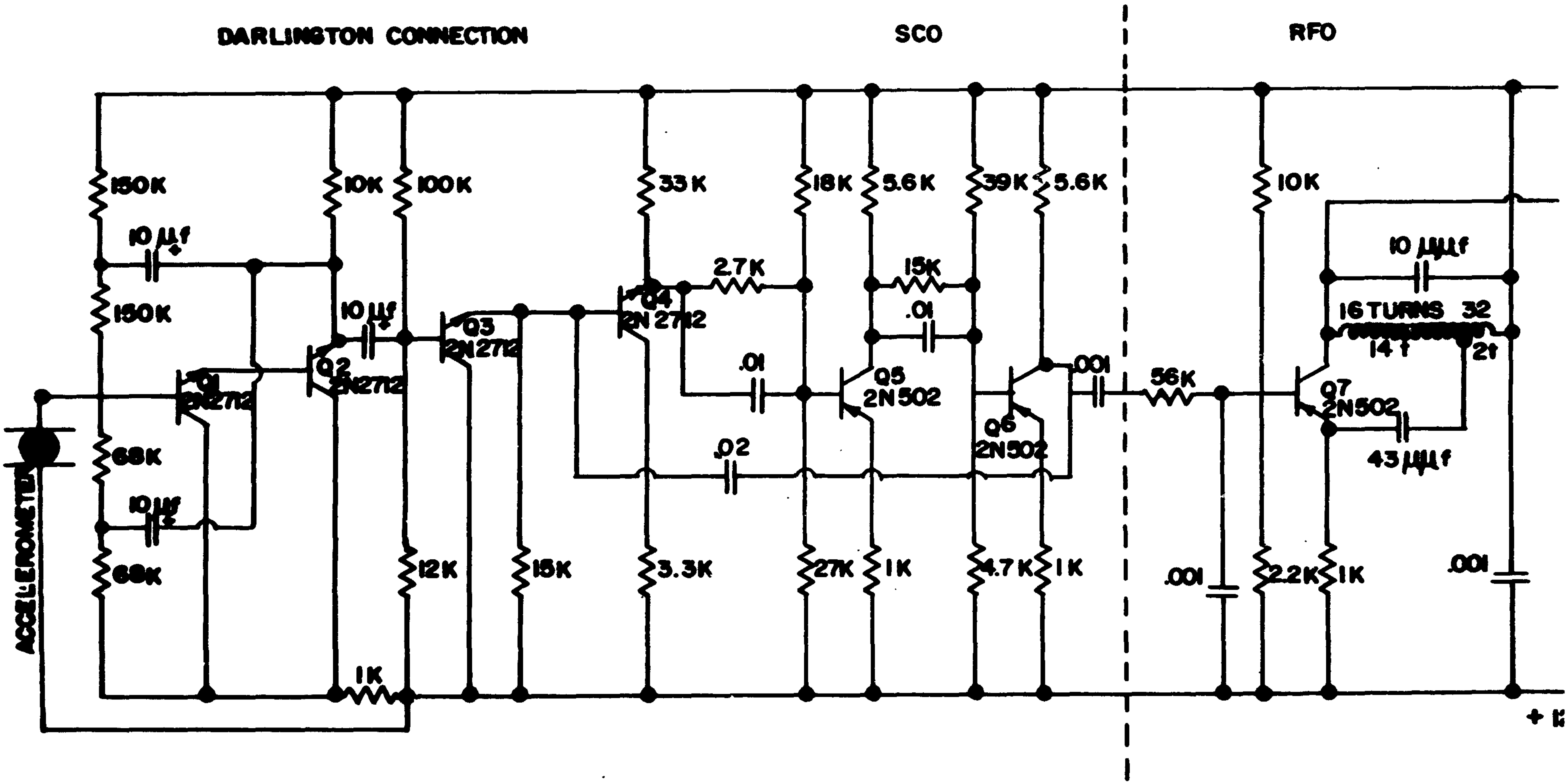


FIG. 10

Fig. 11. Experimental Reentry Vehicle (RVX) Shape for Acceleration Sensing Telemetry - Shown with sabot.

70mc VERTICAL PROBE TELEMETER - FM/FM SYSTEM

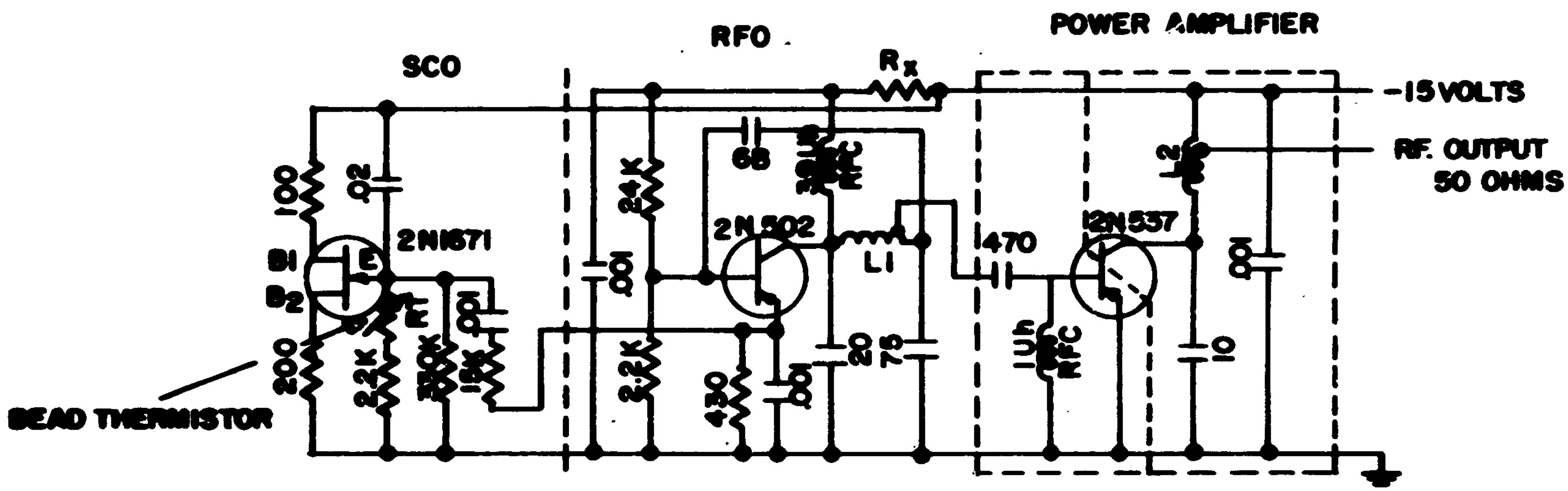


FIG. 12

70 mc HIGH POWER VERTICAL PROBE TELEMETER FM/FM SYSTEM

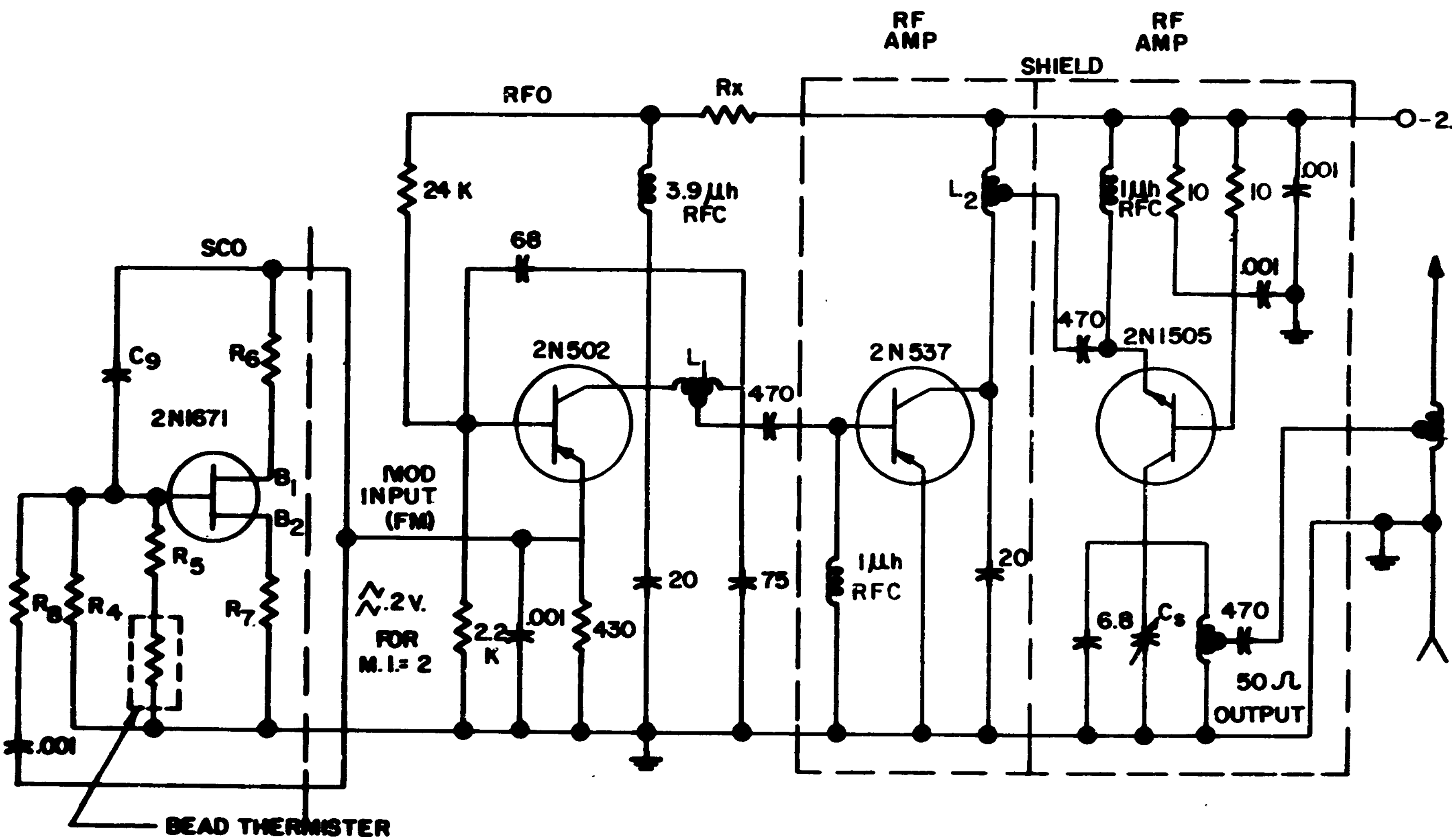


FIG. 13

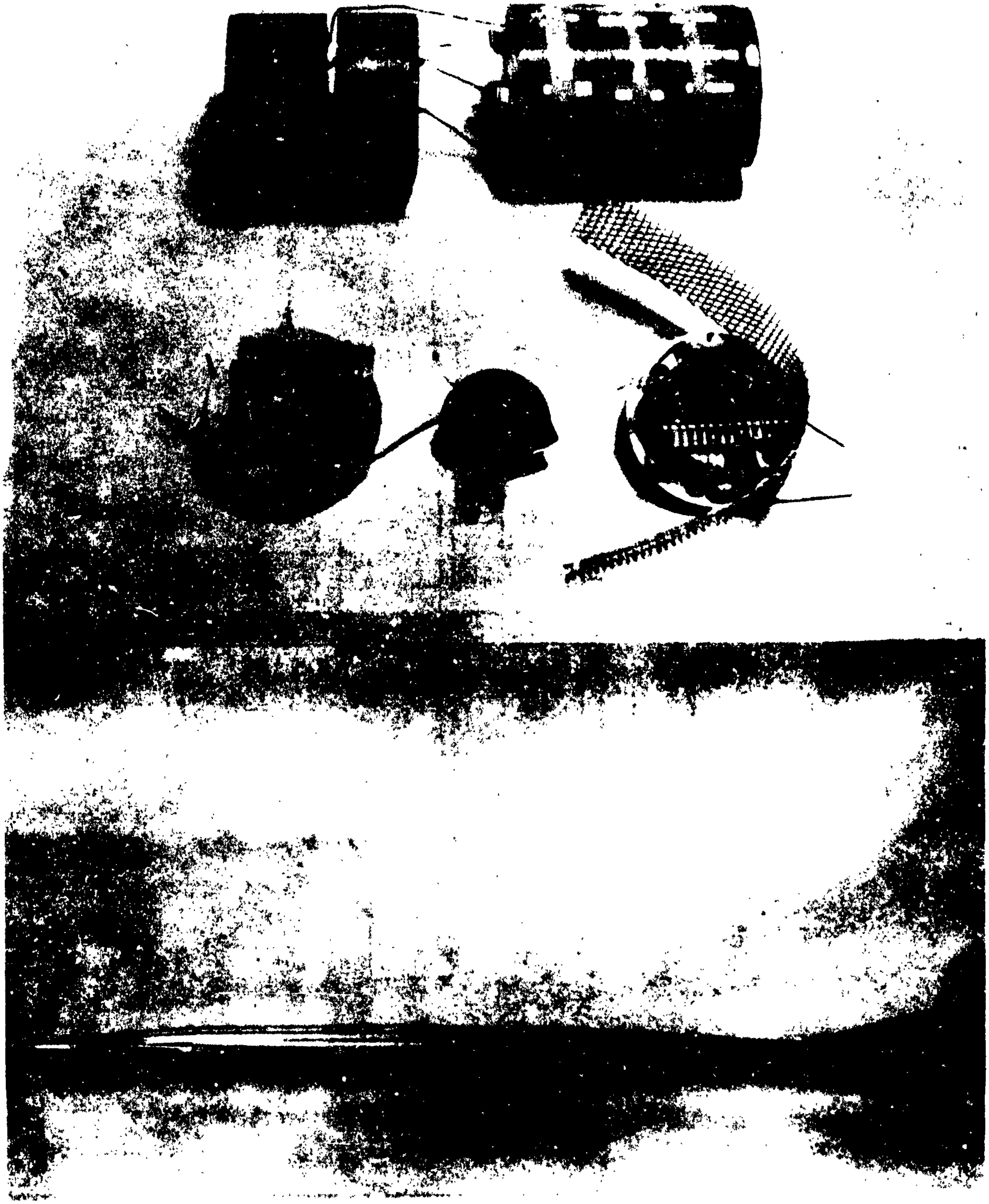


Fig. 14 a. (Top) Sub-assemblies of the vertical probe before and after potting. b. (Bottom) Vertical probe projectile

SCHEMATIC OF RANGE GROUND STATION

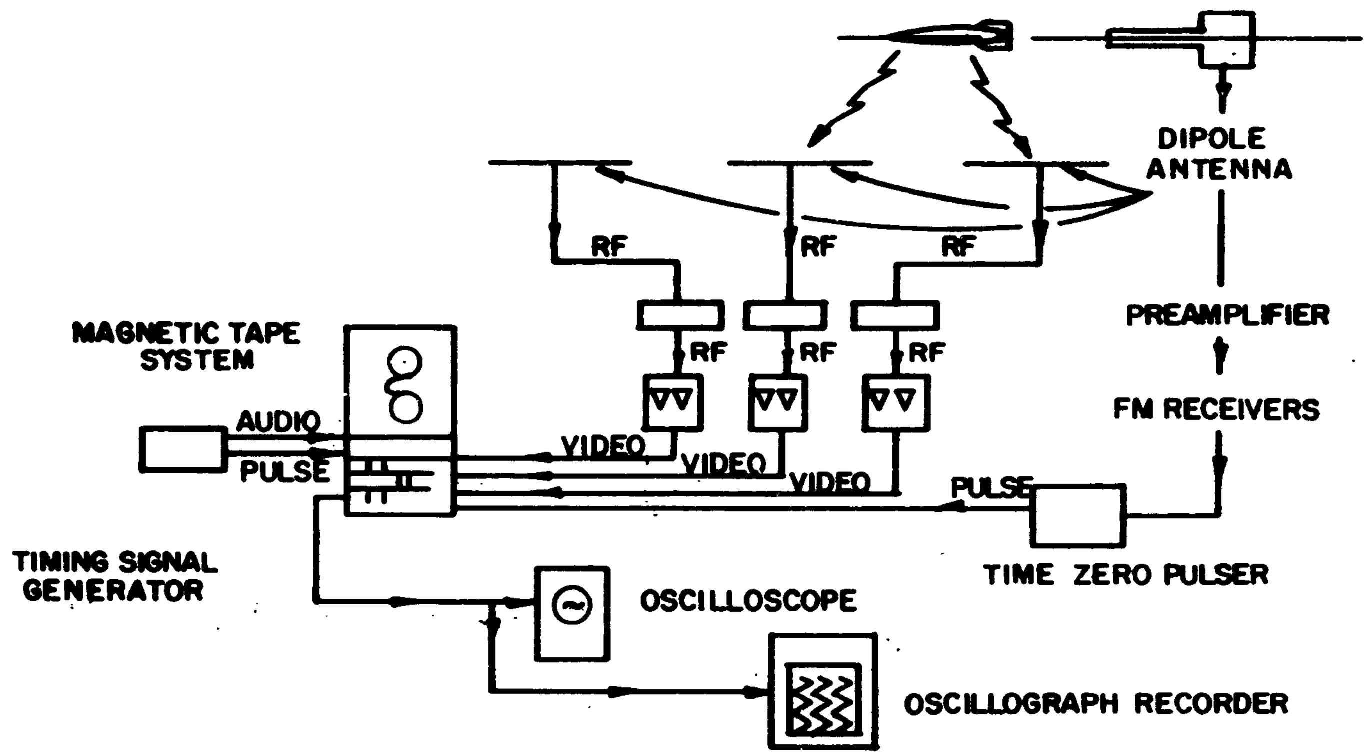


FIG. 15

EXPERIMENTAL RESULTS FROM SHOT SC19

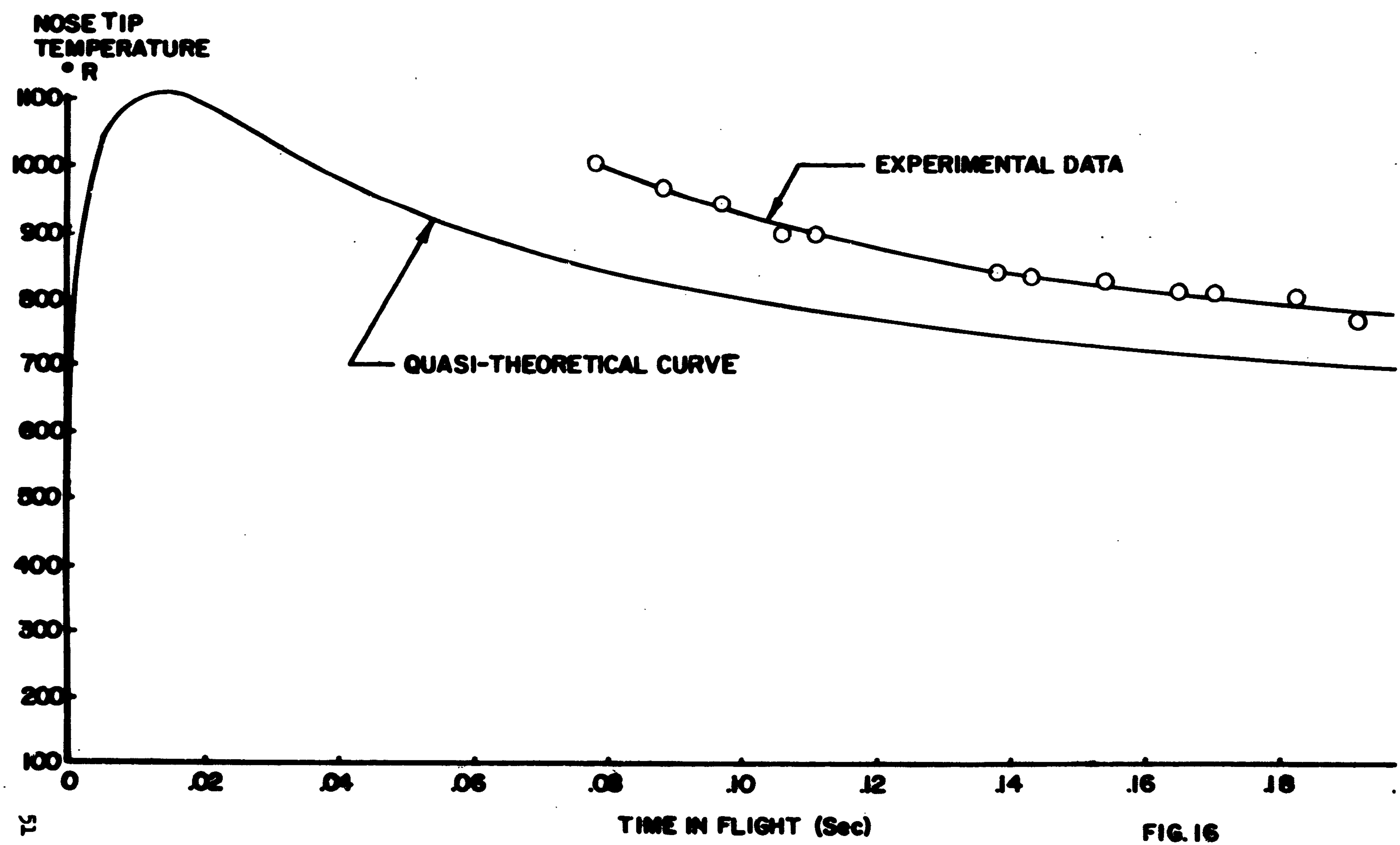


FIG. 16

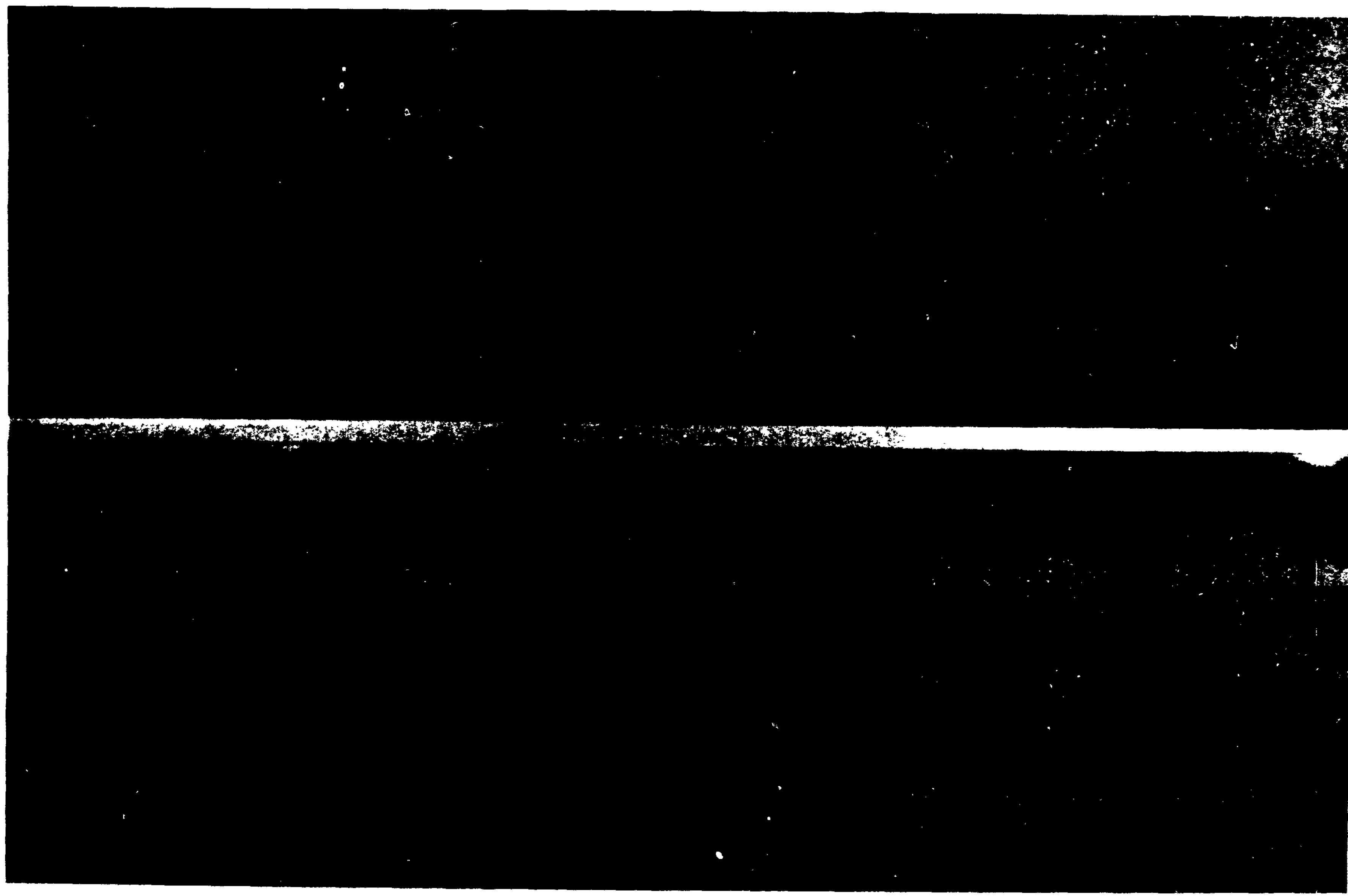


Fig. 17 a. (Top) Temperature telemeter in flight about 30 feet from the gun muzzle. b. (Bottom) Telemeter at about 60 feet from muzzle.

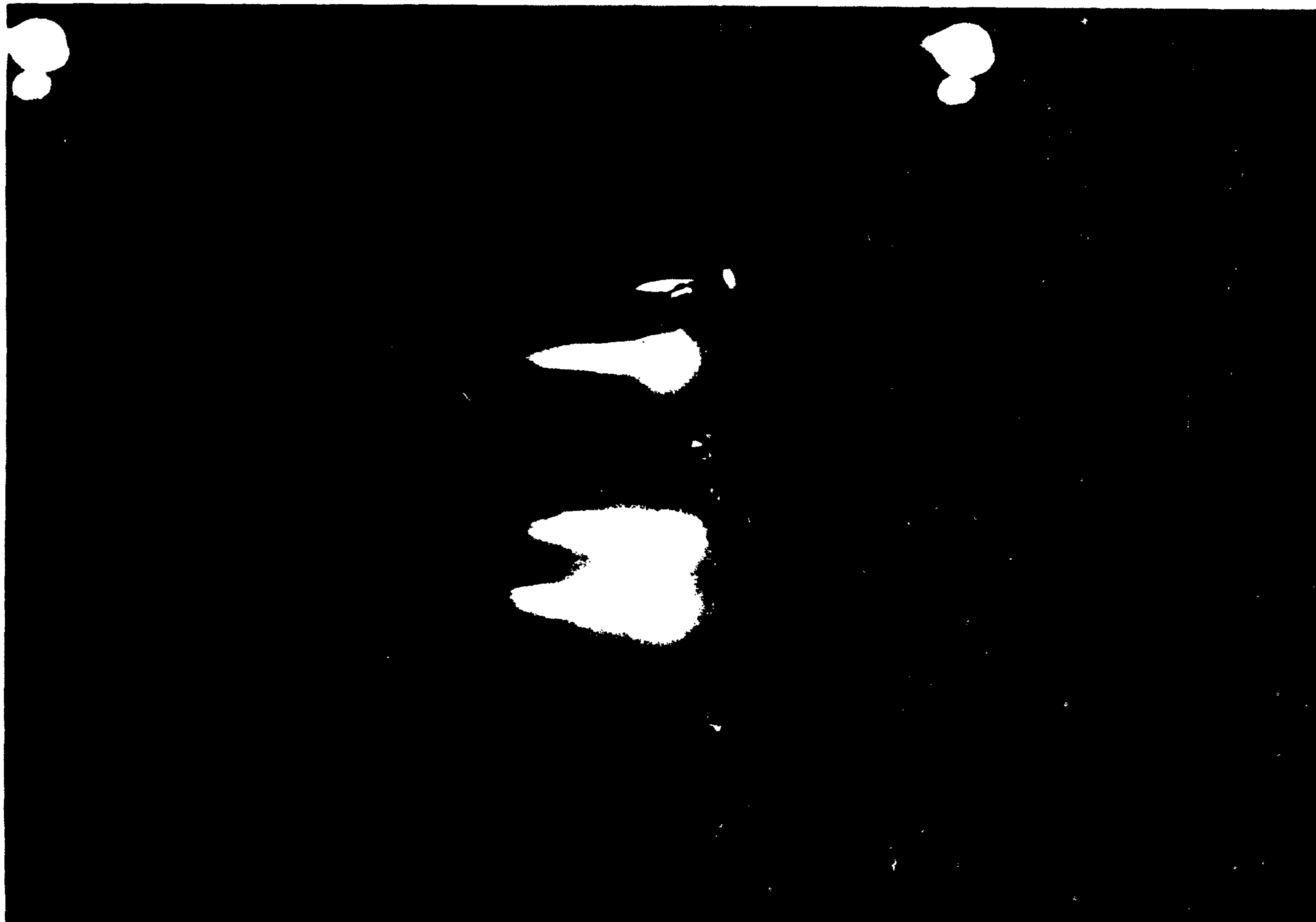


Fig. 18 Temperature telemeter at about [redacted] 7; showing burning sabot fragments.

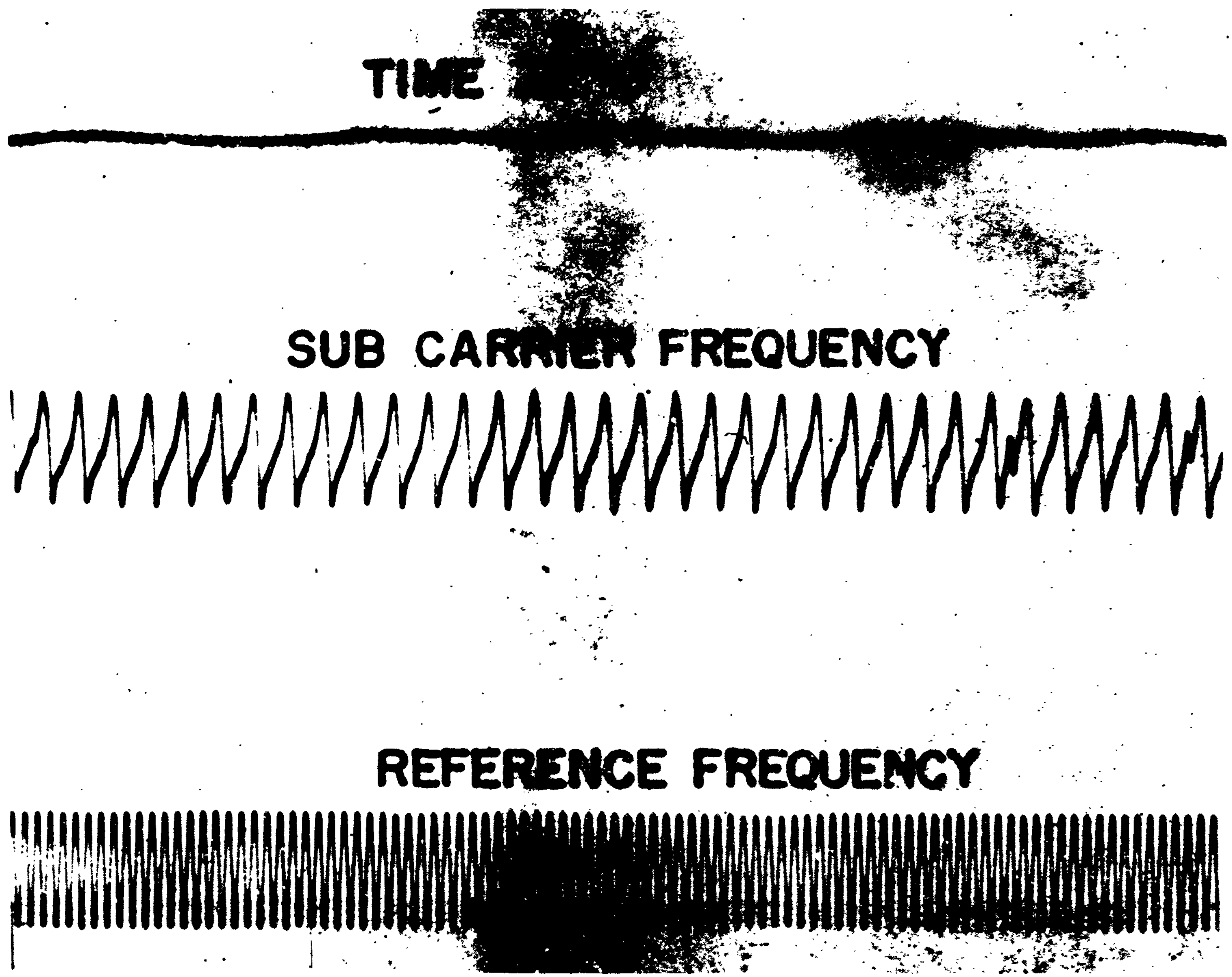


Fig. 19. Oscillograph recording of the sub-carrier oscillator signal during flight. A time zero signal and a reference signal are always recorded simultaneously.

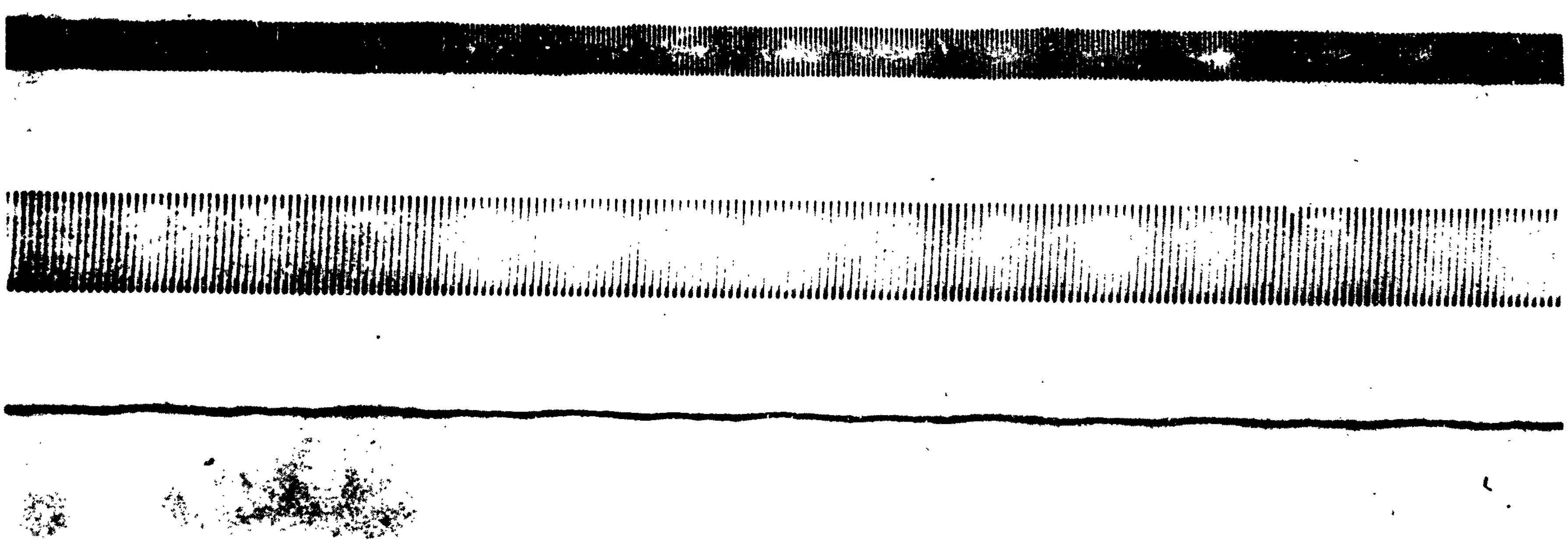


Fig. 20 Oscillograph recording of the sub-carrier signal from a model in flight. The upper trace is a reference signal and the lower trace is the time zero channel.

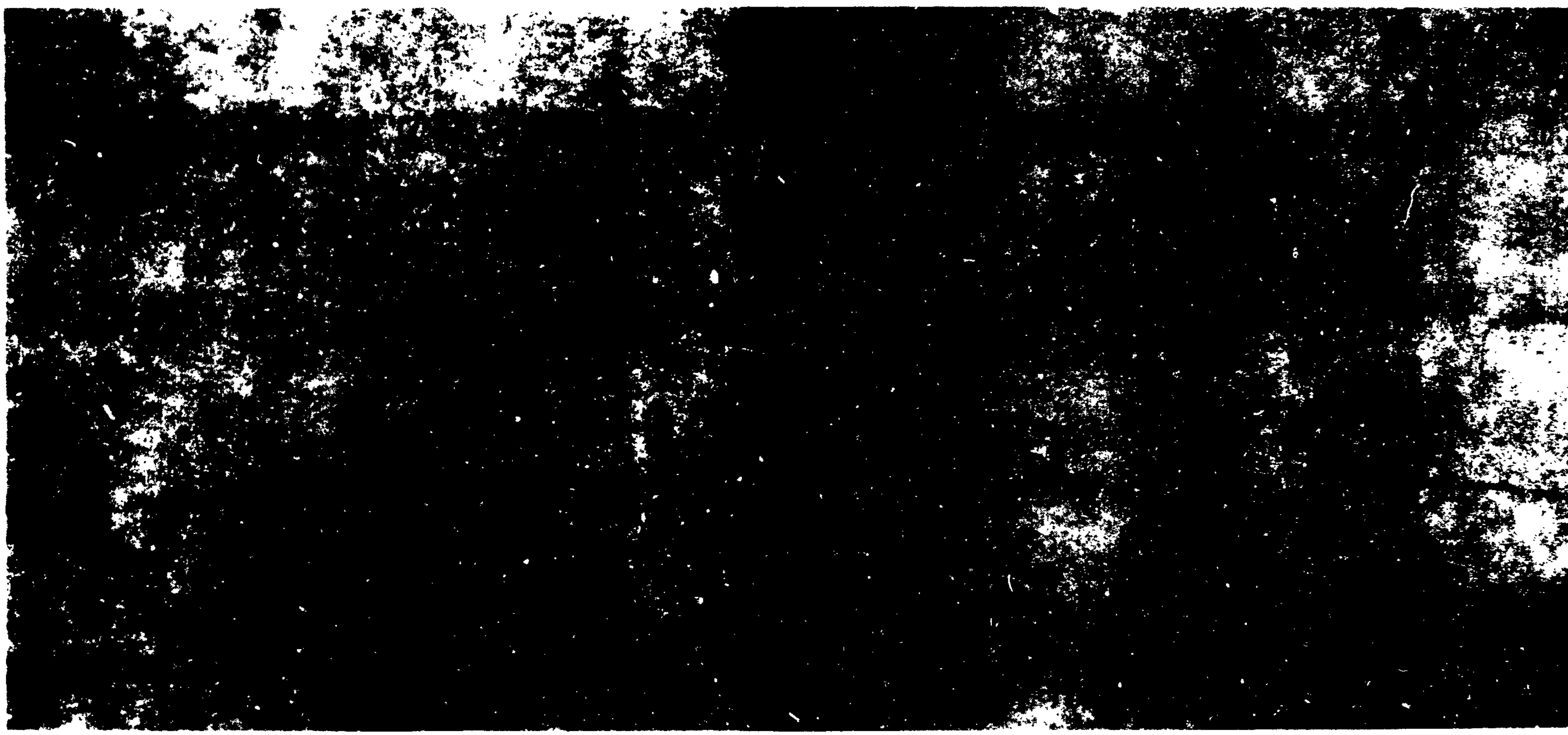


Fig. 21. Oscillograph recording of the in-flight calibrator in operation during a shot.

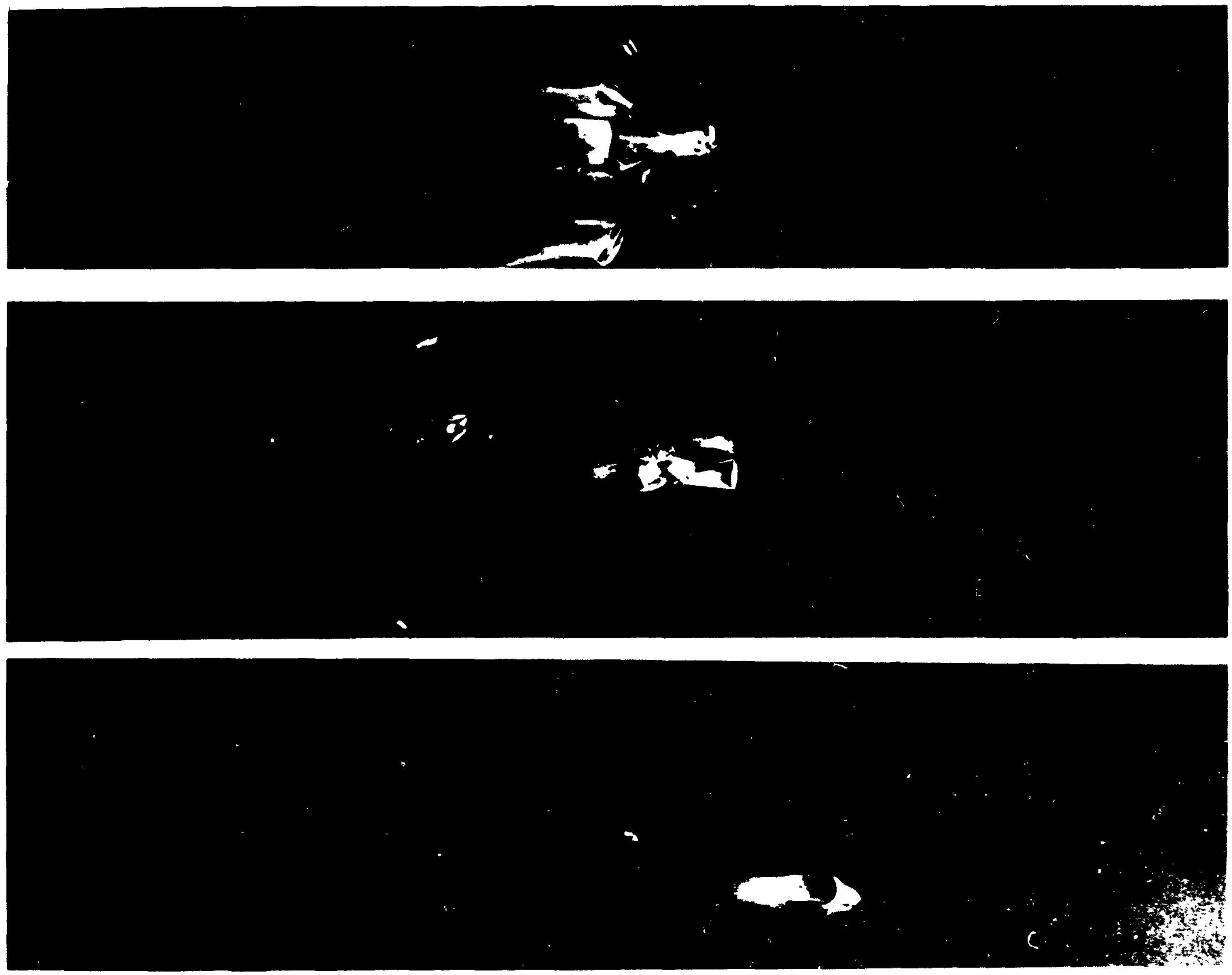


Fig. 22. a. b. c. The break-up of an all epoxy/LP-3 dummy acceleration sensing model due to e excessive "g" loading.

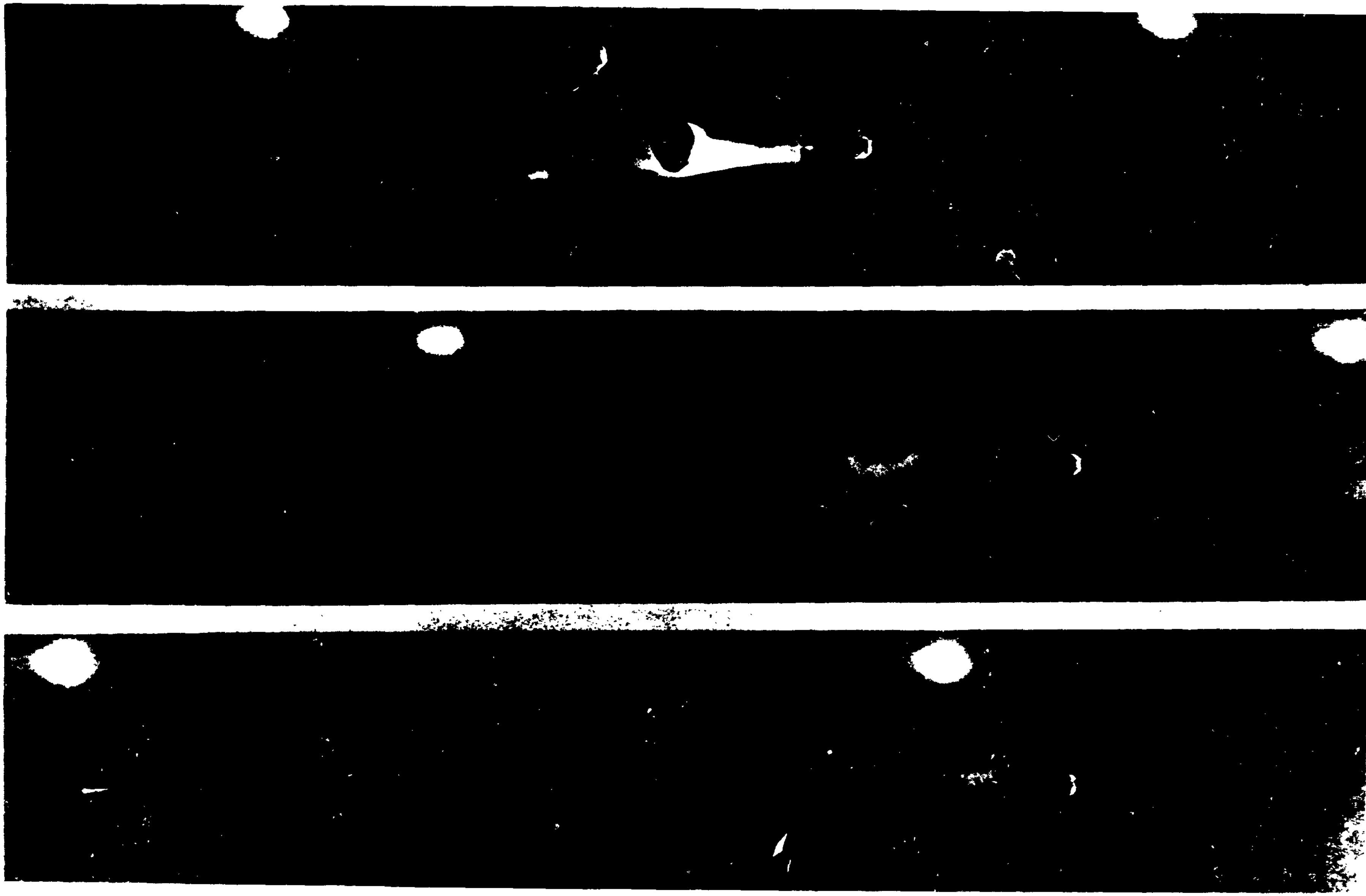


Fig. 23. Three different type roven fiber-glass models in flight. (Top) The flare has broken off. (Middle, Bottom) Good flights, but the nose is burning.

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BRL Memorandum Report No. 1566 April 1964

RDT & E Project No. 1M010501A005

UNCLASSIFIED Report

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